USE OF THE NEAR-SHORE MARINE ENVIRONMENT AS A FIELD LABORATORY BY SCIENCE TEACHERS AND STUDENTS

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CHAPTER I

INTRODUCTION

The marine sciences represent a new frontier of knowledge and a thrilling area of investigation. Research in this area is rapidly expanding on the international, national, and university levels. The United States government is playing an increasingly important role in research and development in the marine sciences. The government is especially interested in the oceans as a source of fresh water and food. Independent organizations are experimenting with the possibility of living for extended periods under the surface of the ocean. The ocean is undoubtedly an important economic resource which, to date, has been tapped only superficially. The opportunities that the marine sciences hold in store for the future are unlimited.

The title "oceanographer" is a misnomer because it is improbable that anyone could have enough knowledge in the disciplines with respect to oceanography to qualify. People now specialize in marine geology, marine biology, or physical oceanography. For a general understanding of the

marine sciences we have to rely on professional literature, symposia, cooperative research projects, and institutes.

Since the marine sciences have become more prominent in the over-all picture of the sciences, certain aspects of the elementary and secondary school curriculum have changed or should change to reflect this prominence. The general science and earth science courses, particularly at the junior high school level, are now including units on the oceans as part of the curriculum. The Earth Science Curriculum Project sponsored by the American Geological Institute is including a unit on the oceans. Most of the National Science Foundation Summer and Academic Year Earth Science Institutes for teachers include some training in the marine sciences.

In Florida, many of the secondary schools that teach general science or earth science include aspects of the marine sciences as part of the program. This is true especially in coastal counties. At least one county in Florida is considering a broad program in the marine sciences as its senior science course, to be taken by accelerated students who have completed biology, chemistry, and physics prior to their senior year.

Marine biology is taught in connection with general

biology; chemistry of sea water is appropriate for general chemistry; physical oceanography is an appropriate topic for general physics. There are applications of all the basic, traditional sciences in the marine sciences, and applications of the marine sciences in all the basic traditional sciences.

This dissertation is especially related to the marine environment, but the techniques and suggestions will have value wherever seas, lakes, or rivers could be used as field laboratories.

By mere geographical position, Florida is the ideal state to utilize the ocean in its science program. The accessibility of the ocean to practically everyone in the state, in addition to the state's reliance on the ocean as a tourist attraction, has made it a part of the lives of the people. This is one of the general criteria for inclusion in the curriculum. There have been some major drawbacks, however. First, much less is known about the marine sciences than other areas. Second, good textbooks in oceanography at the secondary level do not exist. Third, secondary school teachers have little or no training in the area. Fourth, few helpful resources are available for use by teachers.

The worth of the marine sciences as part of the public school science curriculum, especially in Florida, is an established fact. The drawbacks stated above remain to be alleviated.

Purpose of the Study

This study is designed primarily to be a resource for teachers desiring to use the marine environment as a field laboratory to aid and enrich their classroom teaching. The dissertation will be prepared for publication and every effort will be made to make it available to teachers.

Techniques for the identification, measurement, and utilization in the high school science curriculum of selected variables in the near-shore marine environment will be the focus of this study. As an example of how the techniques can be used, a study of the seasonal fluctuation in the population of foraminifera based on a monthly description of the environmental variables will be included in the dissertation. This auxiliary study is intended to be a model which teachers may use.

Foraminifera are marine (usually) protozoans somewhat like amoebas except that they have a shell upon which

their taxonomy is based. It has been found that foraminifera are excellent environment indicators. As such they are important as paleoecological tools in the search for oil and as stratigraphic indicators. Foraminifera are plentiful in the near-shore marine environment, and relative literature is both abundant and readily available.

Review of Related Literature

There have been no papers published in the literature similar to this proposed study. There are many short papers which deal with specific techniques. Generally, these are scattered widely in the literature and are usually designed as aids to university-level students or professional researchers; for example, J. D. H. Strickland and T. R. Parsons, in A Manual of Sea Water Analysis, have covered techniques in measuring marine environmental variables. None are specifically designed as aids for secondary school teachers.

"Plant Communities of Selected Dunes and Sandy Areas of Florida . . . as Laboratories for High School Biology" (Ph.D. dissertation) by W. Y. Bennett in 1961 at the University of Florida is written in a pattern similar to that of the proposed study.

C. J. Flora, in "Marine Biology for High School Science (Ph.D. dissertation), has provided a broad faunal list for the Florida near-shore environment. The author feels that the proposed study, in addition to Flora's, will be a worthy contribution to the resources available to science teachers in Florida.

Few studies similar to the auxiliary study of foraminifera have been published. The only study approaching the scope of the proposed study is A Seasonal Ecological Study of Foraminifera from Timbalier Bay, Louisiana by R. P. Waldron. Most studies include only temperature, depth, and salinity as ecological variables. One excellent general ecological source book relative to Florida is Gulf of Mexico: Its Origin, Waters, and Marine Life, edited by P. S. Galtsoff and published by the Fish and Wildlife Service of the U.S. Department of the Interior. Even these available resources are not widely distributed among or known by secondary school science teachers.

Ecology and Distribution of Recent Foraminifera by F. B. Phleger and Ecology of Foraminifera in Northeastern Gulf of Mexico and Distribution of Some Shallow-Water Foraminifera in the Gulf of Mexico by O. L. Bandy will be principal references in regard to the identification of

foraminifera and the interpretation of ecological data. Treatise on Invertebrate Paleontology edited by R. C. Moore is the basic reference for the taxonomy of foraminifera in general.

Procedures

The author plans to identify and discuss each environmental variable separately. The discussion will include diagrams for building inexpensive apparatus and ideas for learning experiences specifically oriented toward each variable. Each variable will be discussed from the point of view of identification, explanation, measurement, relation to other variables, and relation to the secondary school curriculum. In reference to the latter, the author will make specific suggestions concerning the most appropriate subject (chemistry, biology, etc.) under which each variable would be useful and how it would be most useful. Many of the variables will have application in physics, chemistry, and biology. An important aspect of the study is the role of each variable relative to the curriculum. A vital part of working in the field is knowing the limits of your equipment, when

to take samples, where to take them, and what to do with the data and samples after they have been obtained. This is covered in such a way that it will be readily understood by high school science teachers.

For the foraminiferal study, the procedure was to make sample collections at five stations selectively chosen for their different ecologic environments and to measure a set of environmental variables at each station once per month for a year. Tables have been constructed for each variable showing the changes during the year. The author points out places where statistical correlations might be applicable as part of the discussion on the interpretation of the data. The data, as a whole, are treated with the purpose of helping the teacher understand them. Since little of this type of work has been done, the study is primarily descriptive and reporting of facts. When problems or interesting anomalies appeared, they were investigated or noted as worthy of further investigation.

This dissertation is predicated on the idea that field work is a valuable part of learning experiences in the sciences. A section of the study will be devoted to planning field work in the near-shore marine environment. Included in this section will be: (1) when the use of

field work is appropriate, (2) preparation for field work, (3) organization of field work, (4) operating procedures while in the field, and (5) classroom follow-up.

Data to Be Gathered

The environmental variables to be identified and discussed are: (1) classification of marine environments, (2) currents, (3) pH, (4) temperature, (5) light penetration and turbidity, (6) salinity, (7) substrata, (8) Eh, and (9) dissolved oxygen.

For the foraminiferal study, a total of 60 samples was taken during the year. The total number of individuals is reported, the total number of individuals of the genus Elphidium is reported, and a list of common species of foraminifera present is reported. Environmental data will include: (1) general geology of Seahorse Key, (2) depth, (3) currents, (4) pH, (5) temperature, (6) salinity, (7) light penetration, (8) Eh, and (9) specific substrata.

The data connected with the foraminiferal study will be analyzed in terms of utility for the teachers. The data which will be assembled will not be central to the purpose of the dissertation. It may be anticipated that

readers will get an understanding of the relationship between research activities, resultant data, and generalizations based on the activities and data from the study.

CHAPTER II

CURRICULUM DEVELOPMENT AND THE ROLE OF THE MARINE SCIENCES

> Each generation gives new form to the aspirations that shape education in its time. What may be emerging as a mark of our own generation is a widespread renewal of concern for the quality and intellectual aims of education -- but without abandonment of the ideal that education should serve as a means of training well-balanced citizens for a democracy [Bruner, 1963, p. 1].

Bruner's statement reflects the course that education in the United States has taken in the past eight years. As in politics, conservative and liberal wings have evolved in education. Bitter battles have occurred between members of the two wings relative to the problem of what should be taught in schools, how the teachers should be trained, and how things should be taught. In spite of their differences, both wings would probably endorse Bruner's statement.

On the educational scene today, there seems to be considerable agreement concerning educational objectives. In the shadow of this agreement, tremendous diversity

occurs relative to the means of reaching the objectives of education. However, much agreement has been achieved in the area of means since the "crisis" days of Sputnik. The evidence is the widespread curriculum innovations that have occurred and continue to occur. This is the first time in the history of education in the United States that enough means have been agreed upon to change the curriculum. The school curriculum will continue to undergo change. The curriculum, as it continues to evolve, will reflect our evolving civilization. The end will not be set but will remain changing as long as we, as a culture, change.

Statements of educational objectives have been published by nearly all educational philosophers and many other authors concerned with education. Through the years, several statements are thought to represent education at the time. The famous seven cardinal principles were designed as guidelines for post-World War I education. These objectives are: (1) health, (2) command of fundamental processes, (3) worthy home-membership, (4) vocation, (5) citizenship, (6) worthy use of leisure, and (7) ethical character (Commission for the Reorganization of Secondary Education, 1918, pp. 7, 10-11). The Educational Policies Commission of the National Education Association has

published a series of statements of educational objectives. In 1938, the following objectives were endorsed: (1) self-realization, (2) human relationship, (3) economic efficiency, and (4) civic responsibility. Supporting these objectives are related generalized behavioral objectives. In 1952, a reclassification of objectives yielded:

> (1) All youth need to develop saleable skills and those understandings and attitudes that make the worker an intelligent and productive participant in economic life (economic competency).
>
> (2) All youth need to develop respect for other persons, to grow in their insight into ethical values and principles, and to be able to live and work cooperatively with others (democratic values).
>
> (3) All youth need to grow in their ability to think rationally, to express their thoughts clearly, and to read and listen with understanding (thinking) [Educational Policies Commission, 1952, p. 216].

In 1961, the conclusion of the Educational Policies Commission regarding the central purpose of the schools was:

> Individual freedom and effectiveness and the progress of the society require the development of every citizen's rational powers. Among the many important purposes of American schools the fostering of that development must be central [Educational Policies Commission, 1961, p. 21].

Careful scrutiny of all the statements reveals that they are general and remarkably similar. In order

for objectives to be reached, guidelines for those carrying out the objectives must be specified. These specific guidelines must be in terms of behavioral objectives (Taba, 1962, pp. 206-10). None of the objectives cited is in terms of specific behavioral objectives. The approach to the problem of listing educational objectives in such a way that they are useful in changing the curriculum is most desirable (Bloom, 1956; Krathwohl et al., 1956).

As an example of the technique of constructing useful specific behavioral objectives, French (1957) has begun with the general objectives stated by the Educational Policies Commission of the National Education Association in 1938 and has listed specific illustrative behaviors:

1. Growing toward Self-Realization (General)
   1.1 Developing behaviors indicative of intellectual self-realization
      1.11 Improving study habits, study skills, and other work habits
         1.112 Displays an inquiring mind: is intellectually curious and industrious

Illustrative Behaviors (Specific)
(a) shows by readings and questions his interest in wide variety of problems and endeavors,
(b) perseveres and carries through industriously on an intellectual task which he has accepted for himself,

(c) makes an effort to evaluate his practices to see whether they are consistent with his goals,
(d) takes increasing pride in his workmanship [modified from French, 1957, pp. 92-94].

These illustrative behaviors then can become guidelines for the teacher in his approach to the presentation of subject matter and in his evaluation of student progress.

The teacher must first provide the student with the opportunity (1) to read widely by giving the student access to relevant reading materials, (2) to ask questions by creating a classroom atmosphere which is comfortable physically and mentally for the student, (3) to set some of his own tasks and goals by discussing and guiding him, and (4) to communicate his pride by allowing time for the student to present projects orally, visually, or in writing to some audience (teacher, parents, or class).

Specific behavioral objectives can be determined relative to the marine sciences. Some illustrative behaviors relative to an environmental variable, tides, are:

1. Student reads books and articles from reading list supplied by teacher or finds literature in the library on his own.

2. Student brings to school articles on tides from current newspapers or periodicals.

3. Student asks questions about the effects of tides on life in the tidal zone.

4. Student presents plan for harnessing the energy of the tides for commercial use.

5. Student visits the shore on his own and brings examples of life found there to school.

The curriculum underwent an upheaval in the 1930's and is involved in upheaval presently. The reasons for these upheavals cannot be traced directly to educational objectives. Instead, the reasons can be traced to a revolution of thought within power groups relative to the training of teachers, the specification of appropriate approaches to subject matter and behavioral objectives, and a change in subject matter.

The revolution of thought in the 1930's was inspired by the contributions of Dewey and Kilpatrick. The power group which experienced this revolution was comprised of those in the field of education. The effect on the curriculum was not as great as it could have been because the educators as a group were not powerful enough within the structure of our culture at the time.

Currently, a more substantial upheaval is occurring. It is successful because it is endorsed and actively supported by government, scientists, and educators. These

three groups, especially the first two, are extremely powerful groups in our culture and are respected by the majority of the people. The reason for government and scientists joining educators is that they were both shaken by Sputnik into the realization that the public school curriculum must evolve as society and human knowledge evolve. Curriculum innovations are manifested today in the classroom as a result of (1) the concern of powerful groups and (2) the cooperation of the groups in planning the changes.

The people who are now actively changing the educational scene from the point of view of the curriculum should approach their work in terms of (1) human development, (2) social forces, (3) the nature of learning, and (4) the nature of knowledge (Hass and Wiles, 1965, pp. 3-310). If this approach is valid, the addition of the marine sciences to the curriculum must be rationalized in terms of their contribution to each.

In education human development means the development of the individual from conception until death. Human development is considered to include not only physical growth but also intellectual and social growth. Growth in its broadest sense is synonymous with human development (Dewey, 1963, chap. 4). An individual's ability to

develop intellectually and socially is controlled by his self-concept or how he sees himself (Gordon, 1962, pp. 314-34).

One approach toward developing subject matter within the curriculum in the light of human development is the analysis of persistent life situations (Stratemeyer et al., 1957). Making oral presentations is a typical situation calling for growth in ability to use intellectual power (Stratemeyer et al., 1957, pp. 194 and 195). The expectations for those in early childhood, later childhood, youth, and adulthood vary greatly. This is not to say that each group necessarily has a characteristic cognitive approach.

If members of these groups made oral presentations on subject matter from the marine sciences, appropriate expectations might be:

1. Early childhood -- relating to the class or some other familiar group the interesting experiences remembered from a visit to the beach or on a boat ride.

2. Later childhood -- accurate relation of observations taken on a field trip to the shoreline accompanied by tentative explanations of the observed facts.

3. Youth -- presentation of special study of ecologic factors in the tidal zone supported by observed facts, tentative hypotheses, and an attempt at interpreting causal relations.

4. Adulthood -- observing accurately ecologic factors in the tidal zone, identifying complex causal relations, and relating the special characteristics of this zone to a general understanding of the marine environment as a whole.

These expectations do not preclude the possibility that students in any lower group may overproduce due to factors such as interest, opportunity, and encouragement.

As has been stated in the introduction, social forces are a primary reason for including the marine sciences in the public school curriculum. Heretofore, very little has been known about the oceans other than geography. Now, much research is in progress, and increased research is projected for the future. The marine sciences may hold some of the keys to the future of humanity in the light of the present population explosion. Research is now proceeding in the marine sciences in four vital areas: (1) the conversion of sea water to fresh water, (2) the expanded use of life in the oceans as a source of food, (3) the exploitation of the mineral resources in the ocean and on the ocean floor, and (4) the possibility of people living in submarine domiciles for extended periods of time. All of these indicate that the oceans promise to become important to everyone. Much

more research needs to be done. As more research is done, development and application follow, accompanied by increased employment. There is no doubt that the marine sciences represent a social and economic frontier.

The nature of learning has been of central concern to educators throughout the history of formal education. It is still considered important. The marine sciences offer an opportunity to expand the realm of experiences that are appropriate for learning. Any chance to widen the scope of experiences of an individual plays a role in the individual's growth. The marine sciences offer a source of enrichment within the structure of the present science curriculum. This enrichment may provide interest, opportunity to relate concepts in more than one discipline, or both. For instance, application of concepts in oxidation-reduction reactions can be broadened by consideration of the dynamic, continuing oxidation-reduction reactions on the sea floor, especially in near-shore, muddy environments. The opportunity to participate in field work, the understanding of instrumentation, the limitations of data collected in the field, and the realization that reactions occur continuously in the natural world will all contribute tremendously not only to a student's understanding of

oxidation-reduction reactions but also to his understanding of the methods of science and the relation of science to the natural world. In addition, the marine sciences are glamorous enough and publicized enough to elicit widespread interest among students.

There are aspects of the marine sciences which are appropriate for enriching both the elementary and secondary school science curricula. In general, almost any marine variable (pH, temperature, biomass, etc.) can be presented in a worthwhile learning situation for all children (Bruner, 1963, p. 33). The principal problem is to tailor the subject matter and concepts involved to the needs and capabilities of individual students (see the end of each section in Chapter III).

An example of this can be found in a consideration of the subject matter relative to acids and bases. Acids and bases may be appropriate subject matter for the elementary school science curriculum because many of them are commonly found and used in a child's home environment or because they illustrate a theme or principle such as the variability of liquids in the natural world. Included in this study would be examples of different substances which are acids or bases, how they are used, and why they are

used. As a source of enrichment, reference could be made to various liquids, such as sea water, which are bases.

Acids and bases are also a standard subject matter in high school chemistry. As part of this area, pH (hydrogen ion concentration) is generally studied. The pH of sea water and especially the variability of pH in sea water provide an excellent opportunity for enriching the program by relating the information to conditions in the natural world.

The nature of knowledge in general provides a guide to curriculum development. The marine sciences are an intellectual frontier. Each year the amount of knowledge in the marine sciences approximately doubles (H. K. Brooks, University of Florida, personal communication). It provides an apt example of the tremendous expansion of knowledge which is occurring today. It is an area which has been deleted or inadequately covered in the curriculum to date. In the light of current research, high interest, and projected economic importance, the marine sciences are worthy of inclusion in the body of knowledge which comprises the public school curriculum. Some schools have developed their own units on oceanography to fill this gap. In addition, several National Science Foundation summer

institutes for teachers have been in oceanography. The American Geological Institute is currently sponsoring The Earth Science Curriculum Project at the University of Colorado, which includes a unit on the oceans. The path is clear for some specific innovations and suggestions relative to the inclusion of oceanography in the curriculum.

Oceanography is not a separate subject or discipline. As a result, the study of the oceans represents a special case of physics, chemistry, biology, geology, meteorology, and engineering (H. K. Brooks, University of Florida, personal communication). Present large-scale programs for oceanographic research involve a minimum of four hundred scientists representing all the aforementioned disciplines and a minimum of four million dollars per year in operating expenses.

Consequently, oceanography represents an interdisciplinary area of investigation and is more aptly called the marine sciences. This also suggests that the marine sciences should properly be included within the structure of already established disciplines.

In teaching, the structure of a subject should be emphasized (Bruner, 1963, chap. 2).

> Grasping the structure of a subject is understanding it in a way that permits many other things to be related to it meaningfully. To learn structure, in short, is to learn how things are related [Bruner, 1963, p. 7].

The key generalization primary to an understanding of the marine sciences is that the oceans must be considered as a unit and cannot be simply the sum of isolated parts (H. K. Brooks, University of Florida, personal communication). By the inclusion of the marine sciences as an enrichment of the other scientific disciplines previously mentioned, the student's concept of the structure of each discipline will be improved and the relationship between disciplines clarified by the consideration of the oceans as a unit requiring interdisciplinary, cooperative research.

Many changes have occurred in the elementary and secondary school science curricula. These have generally resulted from large-scale curriculum projects. Current Curriculum Studies in Academic Subjects (Fraser, 1962) gives an adequate review of the recent innovations. The Role of Supervisor and Curriculum Director in a Climate of Change (Leeper, 1965) gives a review of the attitudes and approaches advocated by curriculum experts in the

current curricular upheaval. The Journal of Research in Science Teaching (1964) summarizes the most recent of these studies, including those at the elementary school level. Notable among these studies are the Junior High School Science Project at Princeton University and the Earth Science Curriculum Project at the University of Colorado under the auspices of the American Geological Institute. Both of these projects represent an effort to improve the science curriculum at the junior high school level.

Following are several of the curriculum studies that could be enriched by including aspects of the marine sciences: (1) the Physical Science Study Committee (PSSC), (2) the Chemical Bond Approach Study (CBA), (3) the Chemical Education Materials Study (CHEM Study), (4) the Biological Sciences Curriculum Study (BSCS), and (5) the Earth Science Curriculum Project (ESCP).

The Physical Science Study Committee was the first of the "new wave" curriculum projects, getting its start in 1956 at Massachusetts Institute of Technology. The project developed a new high school physics course with a set of textbooks, films, laboratory guides, and

teachers' guides available commercially in 1960. The course is divided into four parts: (1) The Universe, (2) Optics and Waves, (3) Mechanics, and (4) Electricity and Modern Physics (Fraser, 1962, pp. 7-10).

The Biological Sciences Curriculum Study was developed between 1959 and 1962 under the auspices of the American Institute of Biological Sciences. The course was developed to reach all high school biology students, with separate enrichment materials to challenge gifted students. In order to meet the goal of subject matter flexibility and to reduce the broad scope of biology, three approaches were designed: (1) Ecologic and Evolutionary Approach, (2) Genetic and Developmental Approach, and (3) Biochemical and Physiological Approach (Fraser, 1962, pp. 10-12).

The Chemical Bond Approach Study was developed between 1959 and 1963. The course was intended for use by high school chemistry students. The purpose of the study was to present related topics in chemistry through a fundamental concept of chemical bonds (Fraser, 1962, pp. 12-14).

The Chemical Education Materials Study was begun

in 1960 and the materials were published commercially in 1963. This study approaches chemistry as an experimental science. The emphasis is on laboratory work. The course is intended for high school chemistry students (Fraser, 1962, pp. 14-15).

The Earth Science Curriculum Project is currently being developed. The junior high school science program has long been neglected and now is generally an example of inconsistency, varying often with the whims of respective teachers. This project is aimed at improving the general scientific knowledge of all students in the earth science area.

At the end of each section in Chapter III of this dissertation, specific subject matter in the marine sciences is correlated with appropriate chapters in the curriculum project texts. Since the curriculum project texts are not universally used, subject matter in the disciplines is also correlated with subject matter in the marine sciences. For instance, at the conclusion of the section in Chapter III which deals with light penetration can be found:

1. BSCS (unifying themes) (particularly applicable in Green Form)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change
   c. Science as inquiry

2. PSSC
   a. Part II -- Optics and Waves
   b. Part IV -- Electricity and Atomic Structure

3. CHEM-STUDY
   a. Chapter 4 -- Electricity and Matter
   b. Chapter 5 -- Charge Separations and Energy
   c. Chapter 6 -- Electrical Nature of Matter
   d. Chapter 11 -- Metals
   e. Chapter 18 -- Water

4. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Specific areas within the realm of the marine sciences should be included in the appropriate sections of current science curriculum projects and other curriculum innovations. The marine sciences should enrich the currently evolving curriculum within its present design and should improve the student's concepts of the structure of the respective disciplines. Uniquely in the marine sciences, even high school students may find that

their own exploration and discovery can lead to important contributions not only in their own cognitive development but also in the body of knowledge on the rediscovered frontier -- the oceans.

CHAPTER III

IDENTIFICATION AND MEASUREMENT OF NEAR-SHORE MARINE ENVIRONMENTAL VARIABLES WITH PERTINENT REMARKS FOR TEACHERS

Classification of Marine Environments and Depth

Generally, environments have been classified by whatever is perceived to be significant. The criteria may be any physical, chemical, or biological variable. The most common criterion is depth. Depth alone is not enough, however, to describe adequately an environment. As a result, depth recording is the basic factor in division, followed by other factors which narrow the scope of the environment as needed for the particular purposes of any investigator (light, temperature, pH). This may be termed the descriptive approach and is most commonly used by ecologists in studying present environments. In this case, the physical, chemical, and biological aspects of the environment are equally important, and the classification will be based arbitrarily on the most significant aspect of the environment.

Most of the authorities on the marine environment have derived their own systems of classifications. There is no accepted standard for classification of environments at this time.

Two often utilized classifications are those of Hedgpeth (1957, chap. 2) and Sverdrup et al. (1942, pp. 275-80). (See fig. 1.) The definition of terms in both classifications is based mostly on depth.

Definitions according to Hedgpeth are:

supralittoral: beach or shore just above high water.

littoral: intertidal; bottom between high and low water.

sublittoral: bottom between low water and 200 meters; approximately from low water to edge of continental shelf.

inner sublittoral: between low water and maximum light penetration.

outer sublittoral: between maximum light penetration and 200 meters.

neritic: water mass above the sublittoral.

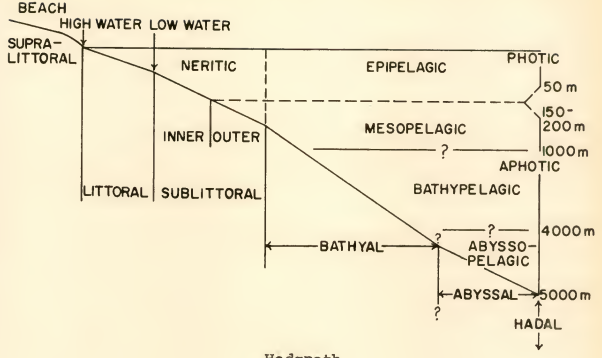
bathyal: bottom from 200 meters to ? (≃4000 meters).

abyssal: bottom from ≃4000 meters to 6000 meters.

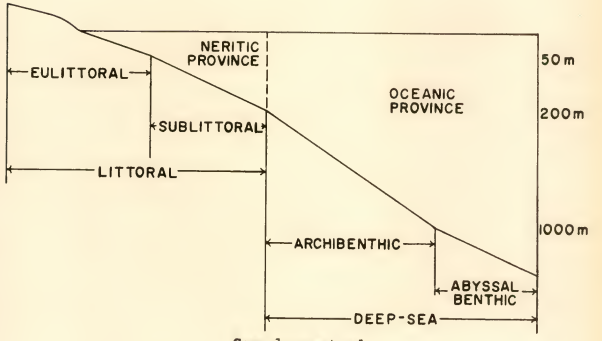
hadal: bottom greater than 6000 meters.

epipelagic: water mass in photic zone beyond the neritic.

mesopelagic: water mass between photic zone and ≃1000 meters.



Hedgpeth



Sverdrup et al.

Fig. 1.--Classification of marine environments.

bathypelagic: water mass between ≈ 1000 meters and 4000 meters.

abyssopelagic: water mass below ≈ 4000 meters.

The definitions according to Sverdrup et al. are as follows:

eulittoral: bottom from beach to a depth of 50 meters.

sublittoral: bottom from 50 meters to 200 meters.

littoral: eulittoral and sublittoral; beach to 200 meters.

deep-sea: bottom from 200 meters on down.

archibenthic: bottom from 200 meters to 1000 meters.

abyssal-benthic: bottom from 1000 meters on down.

neritic province: water mass above littoral zone.

oceanic province: water mass above deep-sea zone.

These are the two most authoritative classifications, but many experts disagree. Terminology in the professional literature is inconsistent, especially for bottom (benthonic) environments, and thus is useless for precise description unless the author clarifies his specific usage. The only way to insure clarity of terminology relative to marine environments is to state the depth or depth range and to describe the environment in terms of the bottom sediment, salinity, temperature, light, or other important environmental variables. If a classification is desirable, choose one from an accessible and authoritative reference. (See table 1.)

TABLE 1

CLASSIFICATION OF ENVIRONMENTS
IN TERMS OF SALINITY

	S °/oo
Infrahaline	0.5
Oligohaline	0.5 - 3.0
Mesohaline	
Meiomesohaline	3.0 - 8.0
Pleiomesohaline	8.0 -16.5
Polyhaline	16.5 -30.0
Ultrahaline	30.0

Source: Hedgpeth, 1957, p. 24.

In much of the literature in biology, environments are classified on the basis of the faunal assemblage and the dominant species present. Many examples of this usage are available. Along the present east coast, two exemplary faunal zones are the Modiola modiolus community and the Mercenaria mercenaria community. Modiola modiolus is a common clam found along the Atlantic coast of North America. This community usually connotes a depth greater than ten meters, always with a rocky bottom and well-circulated water. Mercenaria mercenaria is the large clam so often

used as ash trays by tourists recently returned from a visit to the Atlantic coast. This community occurs in shallow water with a sandy bottom. The depth range is often referred to in the literature relative to an environmental classification. This is true in the study of foraminifera, where the precise extent of a particular species in terms of depth is possible to obtain (Phleger, 1960, chap. 2).[1] Ecologists in a particular area of specialization tend to choose the variable which is the most limiting factor on the life of the group studied as a criterion for classification of environments.

The practice of using a faunal assemblage to indicate an environment is even more prevalent in paleontology because other factors are impossible to ascertain directly. The geographic extent of the living clam, Chione cancellata, is known for the Atlantic coast. Chione cancellata also appears as a fossil in many Pleistocene deposits. By studying the environment of the living clam, one can then postulate that similar conditions probably existed in the past wherever that particular species is found. The

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[1]The depth is determined by either a fathometer or a weighted, graduated line.

extent of Chione cancellata was considerably farther north at times of higher sea level during the Pleistocene, indicating seas and climate were warmer at that time (interglacial periods).

Substrata

A careful identification of the substrata in the near-shore marine environment is desirable as a part of the general over-all understanding of any locality. The character of the substrata affects biomass, local currents, amount of light penetration, pH, and Eh of the environment.

The role of the substrata as an ecologic factor has been underestimated by investigators. This has resulted from the fact that marine biologists and physical oceanographers tend to be poorly trained in geology. Marine geologists, to complicate the problem, tend to analyze the substrata without regard to the surrounding bio- and chemo-physical conditions. The result has been divergent reporting in the literature and a lack of clarity of the role of the substrata in the understanding of the near-shore environment.

As in all oceanographic research, cooperative,

interdisciplinary research is needed. The importance of pooling the knowledge from different areas cannot be overemphasized -- especially to students. The most basic determination regarding the substrata is that of general lithologic type. Most often, shifting, unconsolidated sediments are to be found. Occasionally, sedimentary, igneous, or metamorphic rocks may outcrop. Well-consolidated substrata are most often found along coasts recently denuded by glaciers and submerged by rising sea level like New England or along coasts which are receiving few sediments via rivers like the east coast of Florida. Igneous and metamorphic rocks are easily identified by their crystalline nature and the presence of frequent dikes. The type of rocks outcropping at the shoreline can often be a helpful indicator of the substrata. Sedimentary rock substratum is usually well consolidated and yields fossils.

Samples of the substrata must be obtained for accurate analysis. A diver with some geologic background is the best sampling device. He can observe first-hand what the bottom looks like and can be sure that the sample obtained is representative of the substrata. He can also describe the configuration of the bottom and any local variations. In short, he can function as observer and

sampler in addition to being highly mobile, reliable, and capable of sampling any kind of bottom. From shipboard, it is virtually impossible to sample a hard rock bottom. A diver can simply carry a sledge or geologic hammer with him and load samples into a basket or sack to be hoisted to the ship.

Methods of sampling employed by a diver depend on the purpose of the sampling. In most cases, the Brooks method (see section on Redox) or some similar method is best because the sediment remains relatively undisturbed and some indication of the life on top of (epifauna) and in (infauna) the sediment can be obtained. If a large amount of bottom sediments is needed, manually scooping the material into a container will yield the best results.

Dredges can be used to obtain bottom samples. They are easy to build and easy to operate. Their main drawback is that they do not discriminate in sampling. They scoop the top two or three inches of material which is thoroughly mixed in the dredge, thus obliterating the original relationships of the substrata.

A common sampling device which is efficient for muddy bottoms is a gravity core sampler. This consists of a heavy metal pipe with a core cutter fitted to the lower

end and a check valve and weights at the upper end. The pipe is dropped vertically from the ship and enters the sediment by the force of its own weight. When it is hauled up, the sediment remains in the tube because of the valve. This apparatus can be modified by using a piston instead of a valve. The piston must fit snugly within the pipe and remain at the interface while the pipe penetrates the sediment. A vacuum is thus created which keeps the sediment from slipping out when the pipe is withdrawn (H. K. Brooks, personal communication). These devices are most appropriate when cores including sub-bottom sediments are desired.

Another common bottom sampler which can be operated from the deck of a ship is a grab-sampler. It consists of two jaws controlled by a spring. The spring is cocked by a trigger which is released upon the impact of the device hitting the bottom. This is most appropriate for sampling in deep water.

Unconsolidated sediments have been subjected to a wide variety of classifications. Two broad categories are primary to this classification: sediments of inorganic and sediments of organic origin. If the sediments are more than 70 per cent inorganic, they are classed as from an

inorganic origin. If they are more than 30 per cent organic, they have an organic origin. This is an arbitrary division. In sampling the same bed, one may find adjacent areas which, by definition, should have different origins. Obviously there is a transitional zone in this classification. Seldom do sediments have a single origin.

Within the broad inorganic class are two subclasses based upon the source of the sediments: (1) derived by erosion of rocks, (2) derived by precipitation out of sea water due to chemical conditions in the sea water initiated by density, salinity, and temperature variations (calcium carbonate, gypsum, sodium chloride).

For dominantly inorganic, clastic sediments, size and mineral composition are the chief distinguishing characteristics augmented by the degree of sorting and the degree of weathering. As a standard grade scale according to size, the Modified Wentworth Grade Scale (first proposed by J. A. Udden in 1898 and 1914) has been endorsed by the American Geophysical Union.

In most of the literature the grade limits and the general name are used, while the specific grade name is seldom used (table 2). In order to determine the size and the distribution of particles or degree of sorting in a

TABLE 2

UDDEN-WENTWORTH SCALE

General Name	Grade Limits (millimeters)	Grade Name
Gravel	4096	very large boulders
	2048	large boulders
	1024	medium boulders
	512	small boulders
	256	large cobbles
	128	small cobbles
	64	very coarse pebbles
	32	coarse pebbles
	16	medium pebbles
	8	fine pebbles
	4	very fine pebbles
Sand	2	very coarse sand
	1	coarse sand
	1/2	medium sand
	1/4	fine sand
	1/8	very fine sand
Mud	1/16	coarse silt
	1/32	medium silt
	1/64 (16 microns)	fine silt
	1/128 (8 microns)	very fine silt
	1/256 (4 microns)	coarse clay size
	1/512 (2 microns)	medium clay size
	1/1024 (1 micron)	fine clay size
	1/2048 (1/2 m)	very fine clay size
	1/4096 (1/4)	

Source: Dunbar and Rodgers, 1957, p. 161.

sample according to table 2, sieves with standard openings are piled on top of one another and are shaken manually or mechanically. The A.S.T.M. (American Scientific Testing Machine) Sieve Scale is used (table 3). Unfortunately, an accurate set of sieves is expensive. If highly standardized data are not necessary, home-made sieves using wire screening and hardware cloth can suffice as long as a measure of the openings can be made.

Many common minerals can be identified either by direct observation and laboratory investigation (if specimens are large enough) or by examination under a low-power binocular microscope. The mineral composition is best determined by x-ray diffraction or analysis of thin sections under a petrographic microscope. In most situations either of these methods involves apparatus which is extremely expensive and not readily available.

A general idea of the gross composition of sediments can be obtained easily in terms of percentage by weight. First, dry the sample and weigh it. Heating lightly helps speed the drying process. Second, heat strongly so that organic material is destroyed and weigh again. The difference in weight is an approximation of the organic content of the sediment sample. Third, soak

TABLE 3

A.S.T.M. SIEVE SCALE

Mesh	Opening (millimeters)
5	4.00
6	3.36
7	2.83
8	2.38
10	2.00
12	1.68
14	1.41
16	1.19
18	1.00
20	0.84
25	0.71
30	0.59
35	0.50
40	0.42
45	0.35
50	.297
60	.250
70	.210
80	.177
100	.149
120	.125
140	.105
170	.088
200	.074
230	.062
270	.053
325	.044

Source: Krumbein and Pettijohn, 1938, p. 81.

the remaining sample in weak or dilute strong acid, filter, and weigh again. The difference in weight between step 2 and step 3 is an approximation of the soluble compounds (carbonates, phosphates, and nitrates). Fourth, the weight of the final residue represents an approximation of the relatively insoluble constituents of the sample (oxides and silicates).

The degree of physical weathering is indicated by the size and shape of the particles and the extent of jointing in the particles. Sediments that have undergone chemical weathering have few soluble minerals among the particles. Even the relatively insoluble crystal fragments exhibit frosted crystal faces.

Sediments of organic origin are fairly common, especially in tropical and subtropical environments. These sediments are generally classified according to chemical composition and dominant fossil present. Generally the classification is:

A. Calcareous oozes (more than 30 per cent calcium carbonate derived from organisms)
   1. Foraminiferal ooze (often Globigerina)
   2. Molluscan ooze (often Pteropoda)
   3. Coccolith ooze

B. Siliceous oozes (more than 30 per cent silicon dioxide derived from organisms)

1. Diatom ooze (microscopic, floating marine plants)
2. Radiolarian ooze (floating protozoan related to foraminifera)

C. Bioclastic sediments (calcarous or siliceous fragments of a wide variety of shallow-water organisms like foraminifera, algae, echinoids, and molluscs)

(modified from Sverdrup et al., 1942, pp. 972-73). The only way to determine the type of organisms contributing to the sediment is to wash out the silt and clay and observe a sample in hand-specimen form or under a binocular microscope.

The substratum as an ecologic factor controlling the type of organisms living in or on the bottom is determined principally by the degree of consolidation of the substratum and the amount of energy in the form of currents and wave action which is exerted on the substratum. Barnacles need a firm base and constantly circulating water, so will be found only on rocky bottoms. Some pelecypods (Chione cancellata) live only on sandy bottoms; others (Modiola modiolus) require rocky bottoms. There are countless examples of substrata playing an important role in the ecology of marine organisms.

The study of substrata in the marine environment is essential for any adequate investigation of the sea bot-

tom or the life at the bottom. Elementary school children may be satisfied to discover that bottom sediments are comprised of many things other than sand. The realization and discovery that a handful of mud contains a variety of living organisms can be exciting for anyone. Some ideas for activities using substrata are:

1. Compare substrata from different localities.
2. Trace transitions in bottom sediments locally.
3. Compare the types of life found on different types of substrata.
4. Determine the chemical and mineralogical content of the substrata.
5. Compare the substrata in shallow water to the lithology of the shoreline.
6. Determine the degree of sorting of substrata.
7. Postulate the source of the substrata.

A study of substrata in the marine environment could enrich the following sections of the major science curriculum projects:

1. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Science as inquiry
2. CHEM-STUDY
   a. Chapter 11 -- Metals
   b. Chapter 12 -- Ionic Solids

3. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Temperature

Temperature is the degree of intensity of heat (Sienko and Plane, 1961, p. 16). For the purposes of scientific research, temperature is a quantitative property, although in common everyday usage it is often given a qualitative context. By agreeing upon a standard, a means is achieved for measuring temperature quantitatively and meaningfully communicating this reading.

When one begins working in the near-shore marine environment, temperature is probably the first variable that comes to mind, because it is experienced immediately upon physical contact with the water. This fact is a simple demonstration of its importance. All organisms are extremely temperature-sensitive. Temperature will vary over the course of a year as much as 20°C in near-shore surface waters. Tolerance of such a range by marine organisms requires high specialization, since only mammals (among marine life) have body temperature regulating devices in their systems.

Temperature is a measure of heat. Heat itself is a variable property; therefore, the temperature of the ocean must have a source. As one would expect, this involves both heat gain and heat loss. Heat gain in the ocean is due to: (1) absorption of solar and spacial radiation; (2) convection of sensible heat from atmosphere to sea; (3) conduction of heat through the sea bottom from the interior of the earth; (4) conversion of kinetic energy into heat; (5) heat produced by chemical and biological processes; (6) condensation of water vapor on the sea surface; and (7) radioactive disintegration in the sea water. Heat loss is due to: (1) radiation from the sea surface; (2) convection of sensible heat from sea to atmosphere; and (3) evaporation from the sea surface (Defant, 1961, p. 89). Which combination of factors determining the temperature is most important depends upon the locality. At depths greater than 30,000 feet in oceanic trenches, conduction of heat through the sea bottom from the interior of the earth is probably more significant than condensation of water vapor on the sea surface as a source of heat, whereas the opposite would apply to the near-shore marine environment.

In the near-shore environment, the chief concern

is fluctuation of temperature. The most important factors producing fluctuation are absorption of solar and spacial radiation, convection of sensible heat from sea to atmosphere and atmosphere to sea, condensation and evaporation of water vapor at the sea surface, and radiation from the sea surface. We know from experience that a change in the temperature of the air over a period of time will produce a similar change in the temperature of the water but at a much slower rate.

The transfer of heat between sea and air (liquid and gas) is slow because the surface separating the two is small compared to their respective volumes. Thus, temperature changes in shallow water will occur more readily than in deep water because there is less water involved.

Temperature changes in the sea occur slowly relative to those in the air. When referring to temperature changes in the sea, one usually speaks in terms of changes during a month or a year. This does not mean that changes do not occur during a 24-hour period. Changes do occur. Generally, a maximum is reached at 1400 h (2:00 P.M.) and a minimum at 0400 h or 0500 h (4:00 A.M. or 5:00 A.M.) (Defant, 1961, p. 110). At a depth of six meters (19.8 feet), the diurnal temperature change will be on the order of $0.1^{\circ}C$,

whereas on the surface, the change may be as much as 2°C. If tidal pools are exposed at low tide, the changes may be even greater. This change will be reflected by a reduction in the number of species of organisms which occupy this niche.

For scientific research, temperature can be measured in any of four ways, depending upon the money available and the purposes of the investigator. Two are based on the standard mercury thermometer; one is based on the properties of metal; one is based on electricity.

The standard scale for scientific use is the Centigrade Scale, which is defined by placing the thermometer in melting ice and marking the point at which the mercury thread in the capillary stops as 0°C. When the thermometer is placed in boiling water, the mercury expands to a new position, which should be marked 100°C. The distance between the two marks is then divided into 100 equal parts.

A thermometer calibrated on the Fahrenheit scale may be used, but for scientific reporting the reading should be converted to the Centigrade scale. The conversion equation is:

$$C = \frac{5}{9} (F - 32)$$

where F = Fahrenheit scale temperature and C = Centigrade scale temperature.

One thermometer which is often used is a standard Centigrade-scale thermometer, which can be purchased from any scientific material supply house. It is desirable to have an open scale which is easy to read and divisions to a tenth of a degree. At least once a year, the thermometer should be checked against a thermometer standardized by the National Bureau of Standards. Every U.S. Weather Bureau Station (at local airports) has such a thermometer.

An ordinary Centigrade-scale thermometer is adequate for surface-water measurements and near-shore environments. One should read the thermometer with the scale immersed in the water to the height of the column of mercury. The best way is to read from the instrument as it is immersed directly in the sea. If this is not feasible, dip a bucket of water, place the bucket in a shady spot, and read as quickly as possible. The column of mercury should reach equilibrium in two or three minutes at most. If temperatures are desired from deeper waters, the investigator must get a water sample from the desired depth and measure it quickly on the deck of the boat. These samples can be collected manually if a competent diver is available

simply by taking a closed jar (cork or screw-on) and opening it at the desired depth to let it fill. If no divers are available, or the depth makes diving impossible, a simple sampling device can be assembled (see fig. 2):

1. Tie a rope with markers every meter or fathom to a weighted jar.
2. Tie another rope to a cork cap (or staple the rope to the cork).
3. Fit the cap into the jar.
4. Lower to the desired depth.
5. Pull the cap out of the jar.
6. Allow a minute or two for the jar to fill.
7. Hoist the jar to the surface.
8. Immediately record the temperature of the water.

Another common thermometer which is more expensive is the reversing thermometer. It is used for determining temperatures at depth. This device is composed of a standard Centigrade thermometer and a reversing thermometer (see fig. 3). The reversing thermometer has a large sensing bulb at one end connected to the capillary by an extremely restricted or small passage. At the other end is a smaller sensing bulb. When the device is lowered to the desired depth and is given time to reach equilibrium, the

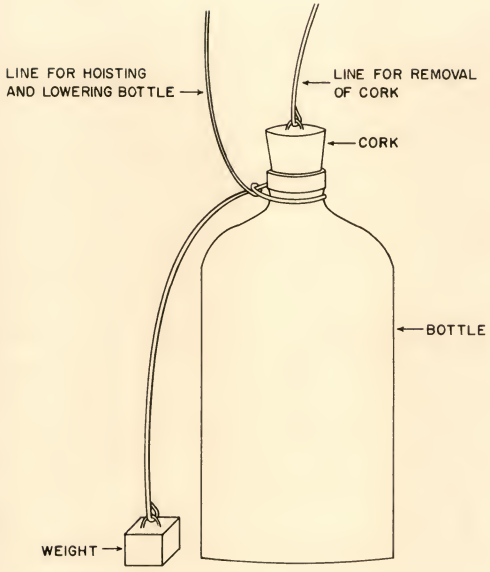

Fig. 2.--Water sampler.

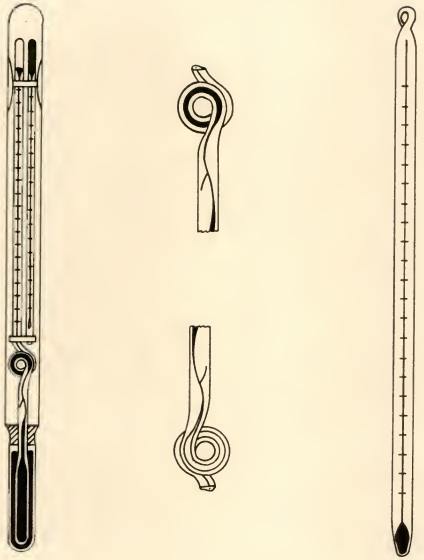

Fig. 3.--Reversing thermometer.

reversing thermometer, which is on a hinge, is turned through 180° by pulling a cord. The mercury thread is snapped at the restriction, isolating the column of mercury appropriate for the temperature at that depth. The device is then brought to the surface and immersed in a bucket of surface water. The reversed column of mercury is read on its scale, and the temperature of the surface water in the bucket is read on the standard thermometer. A correction must be made because of the pressure difference between the surface and the desired depth. The actual temperature at depth is less than recorded because the increase in water pressure at depth forces mercury into the capillary. The equation for correction is as follows (Defant, 1961, p. 35):

$$C = \frac{(T' - t)(T' + V_o)}{6100} \left[1 + \frac{(T' - t)(T' + V_o)}{6100}\right]$$

where T' = uncorrected reading of reversing thermometer, t = temperature of water in bucket, V_o = volume of smaller bulb and capillary expressed in degree units on the capillary scale, and $1/6100$ = coefficient of expansion of mercury. The corrected reading is then $T' + C$. Since the pressure at depth forces the mercury into the capillary, C is usually negative.

The third means of measuring the temperature is with a bathythermograph, commonly referred to as a BT. This is an expensive apparatus which is employed in oceanographic and limnologic research teams. Presently, the chances of a particular school or even a county acquiring a BT are remote. However, in the near future they will become more available through both obsolescence of current types and reduction of building costs. The former will be the first source. Through obsolescence, the Navy and various institutes carrying on research will be able to donate or sell BTs to schools inexpensively.

A BT has a temperature-sensitive metal coil which activates an element that moves a metal pen against a smoked-glass slide, which, in turn, is moved by a pressure-responsive element. The pen thus traces temperature versus pressure on the slide. Since the pressure is a function of the depth, the temperature at given depths can be translated from the marks on the slide. The advantage of this is that a continuous record of the temperature of the water can be recorded each time the BT is lowered. The glass slide is easily removed and the marks preserved by immersing the whole slide in lacquer or other clear hardening solution.

Electric thermisters are a fourth instrument commonly used in research. This is based on the idea that water of varying temperature and density has correlative varying electrical resistivity.

"Temperature is the most important single factor governing the occurrence and behavior of life" (Gunter, 1948, p. 159). This is a broad generality, but if we consider that only a very small percentage of the total number of species in the marine environment have body temperature regulators, the statement is more reasonable. Most marine organisms live in waters with temperatures ranging from $0^{o}C$ to $35^{o}C$. Some forms of algae thrive in hot springs with temperatures up to $85^{o}C$ and some arthropods and pelecypods live in polar seas with temperatures down to $-2^{o}C$. The normal condition with respect to temperature for marine organisms is a variable condition. As a result, each species has evolved a range of tolerance corresponding to the range of temperature which the species has experienced during its phylogeny. Departures from that range can sometimes be tolerated for short periods of time, but not over extended periods.

Heartbeat, nerve conduction, CO_2 production, oxygen consumption, rate of breathing, CO_2 assimilation by plants,

rate of egg cleavage, general activity, etc., can all be grouped under life processes. All organisms have optimum temperatures and maximum and minimum effective temperature thresholds. This means that there are temperatures at which life processes proceed at an ideal rate. These optimum temperatures are characteristic for every species. Likewise, every species will have a characteristic maximum and minimum temperature, the surpassing of which means death. In general, near-shore fauna can endure temperatures from $0^{\circ}C$ to $45^{\circ}C$, while deeper water fauna have maximum temperature thresholds nearer $35^{\circ}C$. The horseshoe crab (Limulus) has a maximum threshold of $46.3^{\circ}C$ in Florida and $41^{\circ}C$ at Woods Hole, Massachusetts (Hedgpeth, 1957, p. 169). A general rule subject to wide limits of variation is van't Hoff's rule: Within favorable limits, physiological processes are accelerated at a constant rate of about two or three times for every $10^{\circ}C$ rise in temperature. This means that within the maximum and minimum temperature thresholds, life processes and temperature are linearly related.

Reproduction of marine organisms is closely related to temperature. Orton's rule states: Breeding occurs at a definite temperature or at the maximum or minimum tempera-

ture of the locality. Generally, rising temperatures induce the development of gonads in marine organisms. Each species will have a distinctive ideal temperature for gonad development. For most marine organisms, fertilization occurs externally. Since sperm cells are extremely temperature-sensitive, temperature determines the success of a species from year to year.

Anyone who has fished for blues, king mackerel, tuna, etc., knows that temperature controls the distribution of marine organisms. They are classed in terms of wide temperature range and distribution (eurythermal) and narrow temperature range and distribution (stenothermal). Most near-shore and floating (pelagic) marine organisms are eurythermal. Generally, seasonal fluctuations in population will occur in the near-shore environment largely because of temperature changes.

Temperature is associated with the size of marine invertebrates. Generally, the larger ones are in polar seas, while the thicker and highly ornamental ones are in tropical seas. This is because the shells (tests) of most marine invertebrates are made of calcium carbonate ($CaCO_3$), which is less soluble in warm water than in cold water. In addition, there are fewer predators in colder waters,

enabling individuals to live longer and grow bigger.

The following generalities are often attributed in part to temperature:

1. Larger size in polar seas.
2. Stenothermal in polar seas, eurythermal in temperate and tropical seas.
3. Polar has more individuals per species.
4. Tropical has more species.
5. Polar depends on intensive blooms and well-defined breeding seasons for reproduction.

The study of temperature as here described seems most appropriate for a biology class. As is the usual case, however, ideas related to temperature are appropriate for biology, chemistry, meteorology, and physics. Ideas for relating temperature to biology in the nearshore environment are:

1. Comparison of egg development times at different temperatures.
2. Determination of optimum, maximum, and minimum temperatures for life processes.
3. How life processes are affected by temperature changes.
4. Can marine organisms adjust to sustained temperature changes?

Ideas relating temperature to chemistry and physics in the near-shore environment are:

1. Determination of temperature gradient for different bodies of water.

2. Relation of temperature and pressure and depth changes.

3. Use of different liquids and solids in measuring temperature.

4. Diurnal temperature changes of different bodies of water compared to land.

Temperature is a fundamental variable in the physical world. Considering the extent to which temperature is a part of our lives physically and through daily reference in interpersonal communications, newspapers, radio, and television, it is a subject appropriate for study even at the elementary school level. Almost all children have seen thermometers, at least by the time they reach the fourth grade. As a result, consideration of the nature of temperature and its role in controlling life could well be studied usefully in elementary school.

The science curriculum projects now affecting secondary education include temperature as part of the course of study. The previous discussion provides appropriate supplementary material for:

1. CHEM-BOND approach
   a. Chapter 5 -- Liquids and Solids: Condensed Phases of Matter
   b. Chapter 24 -- Some Aspects of Biochemistry: An Application of Chemistry

2. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change

3. PSSC
   Chapter 26 -- Heat, Molecular Motion, and the Conservation of Energy

4. CHEM-STUDY
   a. Chapter 1, Section 7 -- Properties and Change
   b. Chapter 1, Section 9 -- Looking at Data
   c. Chapter 1, Section 10 -- Characteristic Properties
   d. Chapter 1, Section 11 -- Is Temperature a Characteristic Property?
   e. Chapter 3, Section 22 -- Temperature-Changing Capacity
   f. Chapter 9 -- Temperature-Changing Capacity
   g. Chapter 18 -- Water

5. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Ocean Currents

Historically, ocean currents have been associated with challenge, mystery, and power. Since they are in evidence at the surface of the sea and explorers' ships

in the past were relatively at the mercy of currents, they have been alternately friend and foe of men at sea. The general pattern of surface sea movements has been known for many years. These movements were recorded on the maps of early explorers. The romantic image of the sea, ocean currents, and courageous men stimulates everyone.

Ocean currents are the principal dynamic factors in the distribution of marine life, water mass, temperature, and dissolved gases. It is precisely because of ocean currents that the oceans must be studied as a unit.

The basic cause of the movements of sea water is solar energy. Many other causes contribute to motion, but energy from the sun is fundamental. The others are generally grouped as primary and secondary forces. Primary forces can initiate movement. Secondary forces are the consequences of water movement or the rotation of the earth and tend to alter the flow of water which is already moving.

Externally derived primary forces cause a direct change in the distribution of masses of water. No change in the properties of the water occurs. Wind is the most familiar force of this type. As the wind blows over the surface of the sea, a force, wind stress, is exerted

tangentially on the interface between the atmosphere and the ocean. This wind stress produces a surface current. Because the sea is a continuous stratified medium, this surface current is transmitted downward. The depth to which this current is effective is a function of the depth of the water, the velocity of the wind, and the viscosity of the water. A wind prevailing on the surface over a period of time will also produce waves. The waves will build up to an optimum amplitude, depending on the velocity and the constancy of the wind. Pressure exerted by wind on the windward flank of each wave causes some surface movement in the direction of the wind. This movement is wind drift.

Changes in atmospheric pressure at the surface of the ocean will cause temporary fluctuations in sea level. Due to these fluctuations, gradient currents will develop, with water flowing from areas of low pressure to areas of high pressure.[1] Pressure gradient currents become most significant to man when hurricanes approach the land. The high tides associated with hurricanes are a result of a

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[1]Gradient current is produced by any sustained difference in pressure between locations in any horizontal plane.

temporary rise in sea level caused by the low air pressures in the hurricanes.

A difference in atmospheric pressure is easily measured at the surface, but pressure differences between two different locations at the same depth may occur which are not easily measured. These also produce a pressure gradient current. Since the effect of atmospheric pressure is transmitted throughout a column of water, it can affect the pressure at depth. Water masses of different density will have different pressures at equal depths, the differences increasing with depth. At greater depths, determining whether a current is a gradient or density current may be a moot point. Since water flows from areas of high pressure to areas of low pressure, there is a tendency for flow upward in a vertical column. This tendency is balanced by the force of gravity and altered by internal forces. The resultant current will be a combination of many interrelated factors.

Periodic tides generated by the pull of gravity of the sun and the moon and the centrifugal force of the earth's rotation initiate ocean currents (see section below on tides). These are particularly important in the near-shore marine environment.

Internal primary forces causing ocean currents are

a function of the distribution of mass within the ocean. This distribution is governed ultimately by the gravitational field of the earth, which is generally uniform on the surface of the earth. Variations of a small order occur and are usually explained in terms of isostatic adjustment of the crust (Bucher, 1957, chap. 2).

All factors causing a variation in density are contributing causes of density currents. Generally, differences in specific gravity of a given volume of sea water are due to differences in temperature and salinity.[1] The movements of density currents are locally convective and turbulent. Several hydrodynamic tendencies work together to cause these movements. Masses of water of higher specific gravity tend to sink below those with relatively lower specific gravity. In addition, colder waters will sink or flow below warmer waters. The density of sea water also varies with the temperature. Therefore any measure of the density must be corrected for the temperature (σ_t or sigma t concept). This will have an effect on the mass properties of sea water.

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[1]Specific gravity is the ratio between the weight of one volume of a substance and the weight of an equal volume of distilled water.

At first observation, one might conclude that a three-dimensional circulation occurs in the ocean with warm waters moving to the polar regions, cooling, sinking, flowing to the tropics, rising, and continuing the cycle. If temperature were the only factor, this would be true. However, tropical waters have a higher specific gravity, in general, than do polar waters because of increased rates of evaporation, excess solar radiation in the tropics, and the sigma t concept. These are the principal factors preventing a general oceanic three-dimensional circulation. Circulation in the horizontal plane occurs between tropical and polar regions, but relatively small amounts of this water move vertically. Downwelling and upwelling are phenomena usually characteristic of tropical and subtropical waters, especially near continental coasts, and are thought to be closely related to prevailing winds (Defant, 1961, pp. 642-56).

Secondary forces affecting ocean currents that are already moving are in three groups: (1) frictional forces, which are a function of contact with other currents, coasts, and the sea floor; (2) centrifugal forces, which are a product of curved boundaries and the rotation of the earth; and (3) Coriolis effect, which is a direct result of the rotation of the earth.

Frictional forces occur whenever a mass of water comes in contact with another mass moving with respect to itself. When an ocean current passes another ocean current, eddying occurs in the region of contact. This eddying serves as a drag, and exchange of water and dissolved nutrients and gases takes place between the two masses.

Centrifugal force is a tendency to move away from the center of a curve represented by the curving flow of a current. It reflects the tendency of a moving body to maintain its speed and direction or to resist a change in speed and direction. At any given longitude, the centrifugal force is the same all the way around the earth. This force decreases from the equator to the respective poles because the speed of rotation decreases. As a result, there is a vector of movement of water in a current toward the equator.

The Coriolis effect is exerted in consequence of the rotation of the earth. It acts upon all bodies moving with respect to the earth at or near the earth's surface. Maximum deflection occurs at the poles and minimum at the equator. It is a direct result of the centrifugal force vector toward the equator. Maximum deflection occurs at the poles, in spite of minimal centrifugal force, because

of the reduced radius of curvature as the poles are approached. In the northern hemisphere, deflection is clockwise (to the right); in the southern hemisphere, deflection is counterclockwise (to the left). This phenomenon is observed most readily in large bodies of water. A common misconception is that it is exhibited when water runs down the drain in a sink or tub.[1]

Two approaches toward the measurement of ocean currents are possible. The Lagrange approach is a measure of geographic movement with time. A floating device is set at the desired depth and is allowed to float freely with the current for a period of time. This is referred to as a measure of the trajectory of the movement of water (Defant, 1961, p. 342). The Euler approach considers the current speed and direction from a fixed position.

Drift bottles have been used to indicate general movement of surface water. Any bottle which can be made watertight and floats is serviceable. A note should be inserted before sealing containing the name and address of the releasor and a request for informing the releasor

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[1]For additional references to ocean currents, the author recommends Von Arx (1962, pp. 140-79); Sverdrup (1942, pp. 389-761); Defant (1961, pp. 382-707); and Pickard (1964, pp. 107-77).

about the date and location of the recovery. For most reliable results, many drift bottles should be released at the same time and location. The distribution of bottles may be a measure of the currents of the top ten meters or more likely will be a measure of the wind drift.

A better indication of water in the upper ocean layers can be obtained by observing the movements of drift poles. These are less likely to be affected by wind drift than drift bottles. Attach a weight to one end of a 15-foot by 2-inch by 4-inch pole so that two to three feet of the pole extend above sea level. The movement of these can be observed from land or from a boat. For a given period of time, the distance and the direction traveled can readily be measured. Their distribution over a long period of time can also be estimated if they are properly labeled following the procedure suggested for drift bottles. Since drift poles are hazards for small craft, they should be clearly marked with paint or a flag or both.

Currents can be measured by a drag device comprised of any broad-surfaced object attached to the boat by a line. The line will point in the direction of the current. The velocity is found by:

1. $F = C_d A D V_f^2 (1/2)$, where C_d is the drag coefficient (relatively constant for most drags of the same shape), A is the total surface area of the drag, D is the density of the water, and V_f is the velocity of the current.

2. a is the angle of deflection of the drag.

3. Mg is the force of gravity.

4. $\tan a = F/Mg$.

5. $\tan a = C_d A D V_f^2 / 2Mg$.

6. $V_f = \sqrt{\tan a} \quad \sqrt{2\ Mg/C_d AD}$.

An approximation of the velocity can be obtained by:

$$V_f = \frac{2\ W \tan a}{A}$$

where W = weight of the drag in water.

Measurements taken daily or weekly should be recorded systematically for a period of time of at least one month, and preferably for a year. The current velocity and direction, being a dynamic and changing quantity, should then be treated statistically. The following is an illustration for a northeasterly current (Defant, 1961, p. 350):

1. Measured velocities are w_1, w_2, w_3 . . . w_n for n observations.

2. Corresponding directions are a_1, a_2, a_3 . . . a_n for n observations (taken clockwise from North 0^o to 360^o).

3. East component $u_i = w_i \sin a_i$; west component $v_i = w_i \cos a_i$, where i = 1, 2, 3 . . . n.

4. The arithmetic means are $\bar{u}$ and $\bar{v}$.

5. The vector mean velocity w is found by $w^2 = \bar{u}^2 + \bar{v}^2$; the vector mean direction a is found by $\tan a = \bar{u}/\bar{v}$.

6. Deviations for particular dates are found by $u_i - \bar{u}$ and $v_i - \bar{v}$, and can be correlated with wind velocity measured at the same date.

A continuous current speed recording device may be constructed easily by attaching a fanlike rotating device with blades or cups (similar to an anemometer) to a speedometer. A car speedometer and an anemometer can be adapted for such use. The drive unit of a car speedometer requires power to turn; it must be adapted so that it moves with relative freedom. Also, care must be taken to waterproof the metal rotating shaft, which is subject to corrosion by sea water. This can be done by inserting the shaft unit in plastic tubing and the drive unit in styrofoam coated with epoxy. A rigid vertical plate attached to the device will act as a rudder, keeping it oriented directly into the current. Weighting may be necessary to keep the device vertically suspended in the water. The speed of the current at any time can be read directly from

the meter. If the diameter of the drive unit is known and the time is known, the average speed can be determined in miles per hour from the total number of miles accumulated on the speedometer.

The direct effect of currents on marine organisms is relative to distribution. Floating (pelagic) organisms are at the mercy of ocean currents. They float with the currents and the organisms which prey upon them follow. Algae, floating foraminifera (many species are bottom dwelling or benthonic), and radiolarians constitute by far the largest populations of life in the sea. In addition, they are the lowest link in the food chain. The distribution of these organisms is entirely the result of currents.

Indirectly, currents have a profound effect on all types of marine organisms. The distribution of nutrients and dissolved gases critical for life in the sea is controlled by currents. This is particularly important to life on the bottom (benthonic life) and attached (sessile) organisms, because they depend on the currents to bring food, oxygen, and carbon dioxide to them.

Most of the bottom-dwelling and attached organisms (bryozoans, pelecypods, corals, etc.) have free-floating larval stages. So even the distribution of those forms is determined by currents.

Activities associated with the observation and measurement of ocean currents can be adapted for students of any age. Since these activities involve boat trips or swimming, they may not be feasible for younger children because of the danger of accidents. The younger children would certainly be deprived of exciting and worthwhile experiences, but few teachers would want to accept the responsibility for the children. From the point of view of safety, not concepts, activities most appropriate for young children are those accomplished from the shoreline or wading in shallow water.

The observation and recording of data from drift poles can be a useful activity at any level in school. Drift bottles are more appropriate for older children because it may be a month or longer before the data are returned, and small children may have forgotten the original activity.

Many useful activities can be centered around ocean currents:

1. Delineation of wind currents and tidal currents.
2. Effect of currents on along-shore drift of clastic sediment.

3. Record of the velocity and direction of dominant currents for a particular area during a given period of time.

4. Energy of local currents during different seasons.

5. Effect of local currents on shoreline life.

6. Comparison between plankton in strong currents and quiet water.

7. Weight and size distribution of sediment per volume of water carried by a current of measured velocity at a given date and location.

For references to curriculum studies to which a consideration of ocean currents could fruitfully be added, see the section below on tides.

Tides

Anyone who has lived near or visited coastal areas has seen the rise and fall of tides relative to the shoreline. Almost everyone can remember his eighth-grade science teacher talking about tides and the gravitational attraction between the earth and the moon. People are certainly familiar with the effects of tides, but the common conceptions regarding the tide-generating forces are generally oversimplified. In spite of this, the nature of tide-generating forces *per se* has been adequately explained

(Defant, 1961, pp. 254-71). The effects of tides have been extensively observed, but much more investigation is needed to explain the observed effects on the seas and the effects on air and the solid earth.

The standard usage of the term tide is relative to the periodic rise and fall of the surface of oceans and other large bodies of water. This periodic movement is not confined to the hydrosphere, but the following discussion will refer primarily to the hydrosphere.

Generally, there are two high tides and two low tides in each day. The average interval between the two high tides is 12 hours and 25 minutes. Tides are retarded 50 minutes per day because the moon relative to the earth is later by 50 minutes per day in its passage over a given longitude, since it takes the moon longer to revolve around the earth once than it takes the earth to rotate on its axis once.

There is a lag of the time of high tide behind the actual transit of the moon past a longitude. This time lag is the mean high water lunitidal interval (Defant, 1961, p. 246) and is relatively constant for a given geographical location. Part of the lag is due to the inertia of the water mass of the ocean and the configuration of the boundaries of the water.

The primary tide-generating forces are the gravitational forces of attraction between (1) the earth and the moon and (2) the sun and the earth-moon system. Equally important is the vector sum of centripetal force and centrifugal force at particular geographical locations.

The gravitational forces exerted between the earth and the moon are directed between the center of mass of the earth and the center of mass of the moon. The magnitude of the force is $F = G\ (m_1 m_2 / r^2)$ where G is the gravitational constant, m_1 and m_2 are the masses of the bodies involved, and r is the distance between the respective centers of mass. At different points on the surface of the earth the magnitude varies according to the distance of the point from the center of mass of the earth and the distance from the center of mass of the moon. The force is directed toward the center of mass of the moon from each point on the earth, resulting in a variation in the directional component of the force.

When considering the effect of the sun's gravitational attraction on the earth, one must consider the earth-moon system rather than the earth independently. Both the earth and the moon revolve together in relatively close association around the sun. If the earth and moon

are considered as a system, the center of mass of the system will be displaced toward the moon from the center of mass of the earth. Since the moon revolves around the earth, the center of mass for the earth-moon system is not fixed, and the effect of the force in tide generation is variable.

Any body moving in a curved path has a force directed toward the center of curvature (centripetal force), which is balanced by a force directly away from the center of curvature (centrifugal force). Centrifugal force is caused by the inertia of the body as it is held in its orbit by a balance between its velocity and its distance from the center of curvature. The centrifugal force generating tides on the surface of the earth is a result of the earth's rotation on its axis and the revolution of the earth-moon system around the sun. Centrifugal force is balanced by centripetal force for the earth as a whole. However, the vector sums of the forces vary at different geographical locations. This inequality of forces generates tides.

Tides exhibit a great deal of inequality. Variable inequality results from factors such as wind and atmospheric pressure. Some inequalities are regular and pre-

dictable. Generally, there are four inequalities: (1) semi-monthly, (2) monthly, (3) declinational, and (4) diurnal. A semi-monthly inequality in the time of high tide occurs as the sun and moon approach the same or antipodal meridians. The graph of high water would show a broad peak at high water and remains relatively high even at low water. The monthly inequality in the tides is due to the elliptical path of the moon's revolution around the earth. The tidal range is greatest at the perigee of the moon's orbit and least at the apogee. The declination of the moon's orbit and the sun's position relative to the celestial equator produces the declinational inequality of the tides. The effect is that the high- and low-water stages will vary in range at different latitudes along the same longitude. A diurnal inequality in tides refers to a difference in height of two consecutive high tides. This may be caused by changes in atmospheric pressure, wind, or resonance effects set up by the configuration of the water mass boundaries (Defant, 1961, chap. 7).

For an estimation of the tidal range, refer to Tide Tables: High and Low Water Predictions . . . published each year by the U.S. Coast and Geodetic Survey, U.S. Department of Commerce, in Washington, D.C. There

are separate tide tables for the east coast and west coast. Do not confuse this pamphlet with a similar one, Tidal Current Tables, published each year by the same organization. These tables refer to tidal current velocity rather than feet above or below mean low water.

For measuring the elevation of the surface of the sea, a standard must be selected from which to measure. The Coast and Geodetic Survey uses mean low water, which is determined statistically. If the survey has no gauge in your area, it will be impossible for you to operate with the same standard directly. However, bench marks have been placed at fixed locations indicating the elevation from mean low water at that location. Bench marks are indicated on all United States Geological Survey (Department of Interior) topographic maps. These marks are common, and any tidal gauge can be calibrated in feet from them.

A tide staff calibrated to tenths of a foot is the most simple tidal measuring device. This consists simply of calibrating any fixed pole or stake. The pole may be attached to a dock, cliff, or piling. Observations should be made every hour to get an accurate record of the tidal range. Such a staff is useful in protected areas where waves do not render the surface of the water irregular.

If a tidal gauge is desired in an area of high-energy wave action, a fixed pipe with several holes drilled near the bottom or an open end below the lowest tide mark will suffice. This pipe may be calibrated the same way as the staff.[1]

In coastal areas where tides alternately expose and cover the sea floor, marine life is greatly affected. Generally, animals in this zone live efficiently both in the water and on land (crabs), burrow into the bottom (clams), or seal themselves from exposure (barnacles). Only the first group can last exposed for extended periods (longer than a tidal cycle). The others die mainly because of starvation if subjected to overexposure. They are attached (sessile) or live in the bottom (infauna) and rely on the sea to bring food to them.

Shorelines with muddy bottoms tend to have a larger variety of species represented. Since mud is relatively impermeable to water, tidal pools and standing water maintain a marine environment at the interface of the bottom sediment and water, allowing micro-organisms such as ostracods, worms, and foraminifera to live in great abundance,

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[1]For automatic recording devices, refer to Rudé, Instructions for Tide Observations (1928, pp. 13-38).

even though tidal flats one-half mile or more in extent may be exposed.

Marine invertebrates are by far the most common organisms found in the tidal zone between high and low water, especially the mollusks (clams, snails, etc.) and arthropods (crabs, lobsters, etc.).

The study of tides is appropriate at any level of formal education. For early elementary grade students who live in coastal areas, it is most needed. Very young children who have visited a beach are aware of tides and have some concept of tidal effects. More advanced students will find the complex, interrelated causes of tides challenging. The techniques that students of different ages would use should reflect their intellectual and conceptual level and the degree of sophistication desired from data. Seven-year-old children would be apt to find marking a spot on a piling and observing the water level relative to it at the same time each day for a two-week period adequate for their needs. A seventeen-year-old person studying physics might want to develop a continuous recording device.

Ideas for activities or investigation are:

1. Each day at a given time for an extended period observe the height of water on a piling relative to a fixed mark.

2. Correlate tidal range with barometric pressure and wind direction and velocity.

3. Compare tidal range at the coast with the tidal range at given distances upstream from a river mouth.

4. Compare the height of the new growth of barnacles on a piling to the scars of an old community relative to the tidal range.

5. Correlate the tidal range with the tidal current velocity over a period of time.

6. List the animals that occupy the intertidal zone and determine the adaptations which enable them to live there.

7. Investigate what forms of life (faunal or floral) rely upon tides to distribute larvae or seeds.

8. Determine the force per unit area of tidal currents on a piling.

Tides can be a valuable supplementary subject for:

1. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change
   c. Science as inquiry

2. PSSC
   a. Chapter 21 -- Motion at the Earth's Surface
   b. Chapter 22 -- Universal Gravitation and the Solar System

3. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Salinity

Sea water is an extremely complex solution comprised of dissolved solids and gases representing all known elements. The total quantity of dissolved solids and gases in ocean water is an important factor in determining the properties of sea water and the ability of sea water to sustain marine organisms. Of the dissolved solids, salts are by far the most abundant; hence the importance of salinity. Salinity is "the total amount of solid material in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized" (Sverdrup et al., 1942, p. 50). Salts are "the neutralization products of an acid-base reaction" (Sienko and Plane, 1961, p. 215). This means that, in general, salts in sea water are ions of alkali metals, sulfate and carbonate radicals, and halogens (see table 4).

Several facts are obvious from table 4. One is that the chloride ion (Cl^-) is by far the most abundant. The sodium ion (Na^+) is the second most abundant. When removed from solution, these two ions combine to form

TABLE 4

COMMON CONSTITUENTS OF SEA WATER AND TYPICAL FRESH WATERS, °/oo

	Normal Sea Water (pH 8.17)		Hard Fresh Water	Soft Fresh Water
Cl^-	19.630	18.9799	0.041	0.019
SO_4^-	2.701	2.6486	0.025	0.007
Br^-	0.066	0.0646	. .	. .
F^-	0.001	0.0013	. .	. .
CO_2 H_2CO_3	0.001	. .	. .	. .
HCO_3^-	0.116	0.1397	. .	. .
CO_3^-	0.012	. .	0.119	0.012
H_3BO_3	0.022	0.0260	. .	. .
$H_2BO_3^-$	0.005	. .	. .	. .
Na^+	10.770	10.5561	0.021	0.016
Mg^{++}	1.298	1.2720	0.014	0.00053
Ca^{++}	0.408	0.4001	0.065	0.010
K^+	0.387	0.3800	0.016	. .
Sr^{++}	0.014	0.0133	. .	. .
Salinity	35.161	34.3159	0.301	0.065

Source: Hedgpeth, 1957, p. 130.

sodium chloride (the mineral halite), which is table salt. The salty taste of sea water is largely due to table salt.

Notice, too, that the salinity is about 34.5 °/oo. The symbol °/oo is read parts per thousand and refers to the definition of salinity, which is given in grams of dissolved solid per kilogram of sea water. The chloride ion comprising about 19 °/oo makes up over 50 per cent of the dissolved solids in the ocean.

Table 5 shows some of the differences in salinity which are found in various bodies of water. Seldom does ordinary lake or river water have a salinity higher than 0.4 °/oo. The most notable exception, Great Salt Lake, is far more saline than sea water.

If salinity is measured far from land, it is usually about 35 °/oo. There are some differences in salinity among the oceans of the world, but they are minor, varying between about 33 °/oo and 39 °/oo. When salinity is measured in the coastal waters, tremendous variation occurs. In areas like the southeast coast of Florida, salinities are about 35 °/oo because the east coast receives little fresh water from rivers and is bathed by the Florida Current (Gulf Stream). On the northwest coast of the Florida peninsula, near Cedar Keys, the salinity

TABLE 5

PERCENTAGE OF DISSOLVED SALTS IN VARIOUS WATERS

Constituent	Sea Water	Lake and River Water (average)	Jordan River Near Jericho	Dead Sea North End	Bear River Near Mouth	Great Salt Lake
CO_3	0.41[a]	35.15	13.11	Trace	21.53	0.09
SO_4	7.68	12.14	7.22	0.31	8.16	6.68
Cl	55.04	5.68	41.47	65.81	32.26	55.48
NO_3	. .	0.90	Trace	. .	. .	. .
Ca	1.15	20.39	10.67	4.73	10.12	0.16
Mg	3.69	3.41	4.88	13.28	4.76	2.76
Na	30.62	5.79	18.11	11.65	20.54	33.17
K	1.10	2.12	1.14	1.85		1.66
Fe_2O_3, Al_2O_3	. .	2.75	1.45	. .	2.53	. .
SiO_2	. .	11.67	1.95	Trace	. .	. .
Sr, Br, H_2BO_3	. .	. .	. .	. .	. .	. .
Br	. .	. .	. .	2.37	. .	. .
	100	100	100	100	100	100
Salinity, °/oo	35.0	.146	.770	192.15	.637	203.49

Source: Hedgpeth, 1957, p. 130.

[a]As HCO_3-

often drops as low as 10 °/oo because it is adjacent to the Suwannee River, and no major oceanic currents provide circulation. The salinity in some of the lagoons off the south coast of Texas is often as high as 100 °/oo because no rivers supply fresh water, and evaporation greatly exceeds precipitation. These three examples illustrate the principal factors determining coastal salinities: ocean currents, rivers, and the ratio between evaporation and precipitation.

Table 6 is a list of some of the elements present in sea water (not including dissolved gases) and their respective estimated concentrations. The list includes 60 elements, and is probably not complete because of the limitations of detecting devices. Many of the amounts seem small when categorized in grams per ton; however, the total volume of the ocean is tremendous ($1{,}703 \cdot 10^{20}$ ml) Rankama and Sahama, 1950, p. 286). There is definitely no shortage of elements in the ocean; the problem is to make their recovery commercially feasible. Many private, institutional, and governmental teams of scientists are working on ways of mining valuable elements from the sea.

A more esoteric problem and one having definite philosophical ramifications is the problem of the origin of the dissolved solids in the ocean. This problem is

TABLE 6

ELEMENTS PRESENT IN SOLUTION IN SEA WATER
(Dissolved Gases Not Included)

Element	Concentration (g/ton)
Cl	18,980
Na	10,561
Mg	1,272
S	884
Ca	400
K	380
Br	65
C (inorganic)	28
Sr	13
(SiO_2)	0.01-7.0
B	4.6
Si	0.02-4.0
C (organic)	1.2-3.0
Al	0.16-1.9
F	1.4
N (as nitrate)	0.001-0.7
N (as organic nitrogen)	0.03-0.2
Rb	0.2
Li	0.1
P (as phosphate)	> 0.001-0.10
Ba	0.05
I	0.05
N (as nitrite)	0.0001-0.05
N (as ammonia)	> 0.005-0.05
As (as arsenite)	0.003-0.024
Fe	0.002-0.02
P (as organic phosphorus)	0-0.016
Zn	0.005-0.014
Cu	0.001-0.09
Mn	0.001-0.01
Pb	0.004-0.005
Se	0.004
Sn	0.003
Cs	approx. 0.002
U	0.00015-0.0016

TABLE 6--Continued

Element	Concentration (g/ton)
Mo	0.0003-0.002
Ga	0.0005
Ni	0.0001-0.0005
Th	<0.0005
Ce	0.0004
V	0.0003
La	0.0003
Y	0.0003
Hg	0.0003
Ag	0.00015-0.0003
Bi	0.0002
Co	0.0001
Sc	0.00004
Au	0.000004-0.000008
Fe (in true solution)	$\leq 10^{-9}$
Ra	$2 \cdot 10^{-11}$-$3 \cdot 10^{-10}$
Ge	present
Ti	present
W	present
Cd	present in marine organisms
Cr	present in marine organisms
Tl	present in marine organisms
Sb	present in marine organisms
Zr	present in marine organisms
Pt	present in marine organisms

Source: Rankama and Sahama, 1950, pp.290-91.

related to the origin of the earth, the origin of continents and ocean basins, and the changes that have occurred on and in the earth through geologic time. Because of the complicated nature of this problem, approaches must be made from different directions.

One approach to investigate the problem of the introduction of dissolved solids to the sea is to study the way in which dissolved salts get into the sea today. The most obvious source is rivers. Table 5, however, reveals that the carbonate ($CO_3^{=}$) ion is the most abundant constituent of rivers, while the chloride (Cl^{-}) ion is most abundant in seas. This can be explained. The bones of marine vertebrates and the tests (shells) of many marine invertebrates require calcium carbonate (CO_3) for formation and growth, accounting for the reduction of the abundance of the carbonate ion. But why should there be a relative increase in sodium chloride? One reason is that sodium chloride will not precipitate readily out of sea water except under extreme evaporating conditions. Thus, one might assume that by knowing the amount of sodium chloride in the oceans and the amount being added per year, the age of the oceans could be calculated. This procedure rests on the assumptions that the only source of sodium chloride

in the oceans is by erosion of land masses and transportation by rivers, and that sodium chloride is not used by organisms, neither of which is true. Rivers are not the only source. The sodium content of marine algae, while variable, is extremely high, sometimes more than 30 per cent. The sodium is found in the algae in the compounds sodium sulfate (Na_2SO_4) and sodium chloride (Vinogradov, 1953, p. 40). So, while this approach is not incorrect, it is insufficient to supply the whole answer.

Another approach is to explore the question: Where else on the earth is sodium chloride found? About 3.8 per cent of all the igneous rock in the crust of the earth is sodium oxide (Na_2O). At first, this sounds small, but 90 per cent of the crust of the earth is made up of igneous rocks! We now have a tremendous source of sodium. Magmas (molten igneous rocks) have many strong acids, among which is hydrogen chloride (HCl), and chemically active gases, among which is chlorine (Cl_2). In magmas at high temperatures, these would all probably be dissolved. Since igneous activity has been highly variable during geologic time (see table 7), there is no way of estimating how many dissolved solids have been contributed directly to sea water by magmas. Certainly they have been a major source.

TABLE 7

GEOLOGIC TIME SCALE

Era	Period	Epoch	Duration (years)
Cenozoic	Holocene	Post-glacial	9 thousand
	Neogene	Pleistocene Pliocene Miocene	28 million
	Paleogene	Oligocene Eocene Paleocene	32 million
Mesozoic	Cretaceous		70 million
	Jurassic		25 million
	Triassic		30 million
Paleozoic	Permian		25 million
	Pennsylvanian		25 million
	Mississippian		30 million
	Devonian		55 million
	Silurian		40 million
	Ordovician		80 million
	Cambrian		80 million
Pre-Cambrian			4 billion

Source: Modified from Kummel, 1961, p. 12.

The primeval oceans undoubtedly had dissolved solids in them also. These primary salts are a third major source of solids in the ocean. There is no known way of estimating the concentration of these salts except by pure speculation. Speculation is often fruitful, but alone it cannot be relied upon to provide answers.

It is possible to assign "absolute" dates to rocks on the basis of the rate of decay of radioactive minerals contained in the rocks. The composition of sedimentary rocks of marine origin should contribute to the solution of the problem. Few patterns are discernible using present techniques. The facts are: (1) Pre-Cambrian rocks have high iron concentrations; (2) calcium carbonate in the form of limestone was dominant from the Ordovician through the Oligocene, with unusually large amounts during the Ordovician, Mississippian, Cretaceous, and Paleogene; and (3) oxides are relatively absent in rocks older than about one billion years. In the light of these facts, one can conclude deductively only that, for some reason, iron was deposited readily at one time, free oxygen was not a common constituent of the early atmosphere, and calcium carbonate is a relatively recent addition to marine sediments.

From the point of view of biology and paleontology, any drastic change in the salinity of the oceans in general would be reflected in physiological changes in the marine organisms found in the fossil record. For life processes to continue in marine organisms, an osmotic balance between the organism and the sea water must be maintained. Either organisms are stenohaline (confined to sea water of little salinity variation) or euryhaline (able to endure a wide range of salinity variation), in which case osmoregulatory devices are evident in the physiology of the organism. No worldwide trends of this nature have been discovered in the fossil record.

On the basis of the evidence presented, there is no evidence of large-scale changes in the salinity of oceans during the past billion years at least. One can conclude, then, that (1) marine organisms use sodium chloride and other dissolved solids certainly; (2) possibly the volume of sea water has increased proportionally to the increase in dissolved solids; or (3) the answer lies in some area not yet considered. Certainly all three are contributing factors and need more investigation. The question, "From where did the dissolved salts in the ocean come?" is not yet answered satisfactorily although

a classic hypothesis has been published by Rubey (1951).

Measuring the salinity of sea water is a simple matter if highly accurate results are not necessary. Four techniques are described in the following discussion. Since the composition of sea water remains relatively constant in spite of changes in salinity (i.e., the proportion of Cl^-, Na^+, etc., in the total salinity varies only slightly), a measure of the chloride ion (Cl^-) or the specific gravity is also a function of the total dissolved solids.

Standard Hydrometer

One technique is to measure the specific gravity of sea water, measure the temperature of the sea water, and convert the readings to salinity using standard tables (Zerbe and Taylor, 1953). The procedure is:

1. Use a hydrometer with a range from 1.000 to 1.070.
2. Use a 1000 ml (one liter) cylinder.
3. Use a standard centigrade-scale thermometer.
4. Wash the cylinder and hydrometer thoroughly with sea water.
5. Fill the cylinder with enough sea water to float the hydrometer easily.

6. Place the hydrometer in the sea water in the cylinder.

7. Read the specific gravity from the scale on the hydrometer.

8. Take the water temperature at the same depth as the specific gravity sample (important because surface waters sometimes are contaminated by recent rains).

9. Keep notes on:
   a. Location
   b. Depth
   c. Temperature
   d. Specific gravity
   e. Date

10. Convert to salinity using standard tables.

Home-made Hydrometer

If no money is available to purchase a hydrometer, a simple device may be constructed in the laboratory (see fig. 4).

1. Fill a large flask with one kilogram (approximately one liter) of distilled water.

2. Record the temperature.

3. Obtain a long narrow tube (approximately 0.5 inches in diameter and 10 to 12 inches long).

4. Put sand or lead shot in the bottom of the tube and cork the top so that it is waterproof (seal with lacquer or a similar substance).

5. Float the tube in the distilled water.

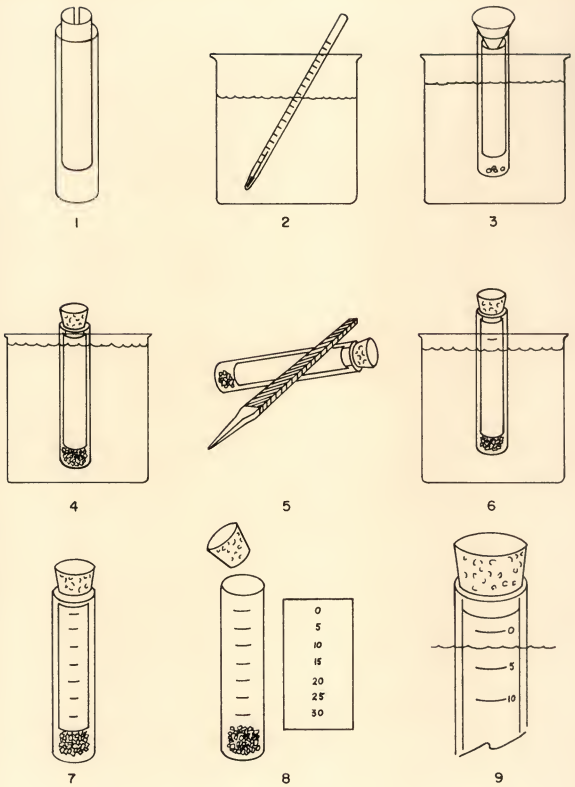

Fig. 4.--Construction of a simple hydrometer for testing salinity.

Source: Flora, 1957, p. 250.

6. Add sand or shot until the tube is stabilized and floating with about two inches emerged and the balance immersed.

7. Mark the outside of the tube with a file at the meniscus. This is the 0 point or the depth to which the tube sinks in water with salinity 0.

8. Add five grams of sodium chloride (table salt) to distilled water; stir until completely dissolved. Mark the tube again with file and label "5". The scale may be directly on the tube or on a scroll of paper inside the tube.

9. Repeat until 40 grams have been added.

All subsequent salinity readings should be made after the water samples have reached the same temperature as the temperature of the distilled water at the time the hydrometer was made.

pH Meter

A third technique is to use a standard pH meter with a silver electrode coated electrolytically with silver chloride. Following carefully the instructions for standardization and operation of the meter, the chlorinity may be read from the meter. This is a direct measurement of the chloride (Cl^-) ion in a solution.

Titration

It is also possible to determine salinity by titration with a silver nitrate solution. In this method, "the precipitable halide halogens in a 10-ml volume of sea water are determined by titration with a silver nitrate solution using a chromate end-point, the Mohr titration" (Strickland and Parsons, 1960, p. 19).

For this method some special apparatus and equipment are necessary:

> An automatic 10-ml pipette and an automatic zero adjusting 25-ml burette are required. An automatic dispenser of diluting solution, containing the chromate indicator, is advantageous. The titration is carried out in a 200-ml tall-form beaker, with magnetic stirring, against a white background in "yellow" artificial light from an ordinary electric light bulb. Lubricate the pipette top with a little glycerol and the top of the burette with a trace of paraffin (not silicone) stopcock grease. The volumetric glassware must be kept spotlessly clean by soaking periodically for a few minutes in a cold 5% solution of sodium hydroxide in methyl alcohol and then rinsing with nitric acid followed by distilled water [Strickland and Parsons, 1960, p. 19].

Any glass or plastic sampling bottle may be used in collecting the sea water to be tested. The top should be tightly screwed on, or, if a cork is used, seal it with a little paraffin. The sample bottle should not be

opened until the salinity determination is ready to be made.

The procedure for determining salinity follows:

> Dissolve 49 grams of good quality silver nitrate for each litre of final solution. Use distilled water and store the solution in a dark bottle. . . . The solution should be well mixed in the bottle once each day or prior to each batch of titrations.
>
> Dissolve 3.5 grams of analytical quality potassium chromate, K_2CrO_4, in each litre of distilled water.
>
> Add the (10 ml) sample of sea water to a 200-ml spoutless tall-form beaker by means of the automatic 10-ml pipette and then add 15 ml of indicator-diluent solution (potassium chromate solution). Titrate the solution (silver nitrate solution) from the 25-ml automatic burette. About 1 ml before it is judged that the end-point is reached, rinse the sides of the beaker and stir with a little distilled water from a wash bottle. As the end-point approaches, the localized red precipitate formed by the silver solution will begin to spread throughout the solution. At the end-point the pale greenish-yellow of the contents of the beaker changes to a full yellow and then becomes a definite pale red as the end-point is exceeded. The exact point is largely subjective. [Strickland and Parsons, 1960, p. 20].

Throughout the titration, the temperature of the silver nitrate solution should be kept from $1^{\circ}C$ to $4^{\circ}C$ higher than the temperature of the sample solution.

For more accurate results, precede the titration by standardizing the silver nitrate solution with a sea

water standard of known chlorinity.[1] The resultant reading is then in milliliters per 10-ml solution of sea water accurate to 0.01 ml. If V = the reading on the burette taken to two decimals, and if C_b = the burette correction (positive or negative) as given by the burette manufacturer (rarely exceeds $\pm$ 0.05 ml), then the chlorinity per liter at 20°C = V + C_b. If the silver nitrate has been standardized, a standardization correction, C_s, should be added so that $Cl/l_{(20°)}$ = V + C_b + C_s where $C_s < 0.15$ ml. The salinity is determined by the equation:

$$S\ ^{o}/_{oo} = 0.02 + [1.8050 \times Cl/l_{(20°)} \times 1/D]$$

where s $^{o}/_{oo}$ = salinity in parts per thousand and D = density of sea water at $Cl/l_{(20°)}$ (use hydrometer).

An induction salinometer may also be used. Since sea water is a good electrolite due to the presence of ions, the electric conductivity of the water is a function of the salinity. All that is needed for this device is a power source, an anode and cathode, and a galvanometer.

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[1] "Eau de Mer Normale" is a sea water standard and may be purchased from chemical supply companies or directly from Depot d'Eau Normale, Laboratoire Hydrographique, Charlottenlund Slot, Copenhagen, Denmark.

Effect of Salinity on Marine Organisms

Salinity affects organisms in diverse ways. The effects are associated with the problems of interaction between a complex solution, sea water, and a living organism. This interaction is primarily osmotic. Osmosis is the migration of molecules from a dilute to a relatively more concentrated solution through a semipermeable membrane (Hedgpeth, 1957, p. 133). Whenever the salinity is increased, the vapor pressure of the solution is decreased, producing a diffusion gradient so that water molecules will migrate from a lower-salinity environment to a higher-salinity environment.

"The primary problem of life in aquatic media is the maintenance of the optimum concentration of water and salts in the internal body fluids through osmoregulation" (Hedgpeth, 1957, p. 134). Marine organisms are either euryhaline or stenohaline. In general, the euryhaline organisms are capable of enduring a range of salinity by changing their own body fluid concentration to that of the surrounding sea water or by shutting off the osmotic exchange between themselves and the sea water, thus maintaining the internal fluids at a specific concentration.

Many invertebrates will absorb water when immersed

in sea water of lower salinity than the salinity of their body fluids. If the salinity is extremely low, the volume of the organism will increase until its structure cannot persist, in which case death occurs. Other organisms will adjust by losing salts osmotically and through enlarged excretory glands. Specialization of excretory organs is one way of achieving osmoregulation. Another way is by specialization of respiratory organs. This enables oxygen (O_2) consumption to vary. Since energy is required to push out salts against a diffusion gradient in low-salinity sea water, an increased supply of oxygen is needed. Actually, then, oxygen consumption may be proportional to osmoregulatory activities in some marine organisms.

The common oyster (Crassostrea virginica) and the blue crab (Calinectus sapidus) can be found in waters varying from 3 °/oo to over 35 °/oo. The oyster adjusts mainly by closing its valves tightly and by changing its volume. The blue crab can be found in 35 °/oo sea water or even in fresh water. Tolerance to lower salinities is built by the reduction of gills, thus reducing water exchange.

Often marine organisms can be found living in rivers right along with nonmarine organisms. Crystal River and Homosassa Springs on the west coast of peninsular

Florida provide examples of this. Since the water in both areas is derived largely from springs emitted from the Ocala limestone, the calcium content of the water is high. Calcium is deposited on the cell membranes in the organisms, inhibiting permeability and allowing sheepshead, snook, jack crevalles, and other ordinarily marine organisms to thrive in the fresh waters.

In general, the marine organisms in near-shore environments are euryhaline, with tolerance ranges exceeding the salinity ranges that occur in the natural environment (Hedgpeth, 1957, p. 147). This is especially true for life in bays with good circulation and estuaries. The organisms in isolated lagoons and on coasts bathed by ocean currents of relatively constant salinity are more likely to be stenohaline and thereby be distributed in definite zones or communities. The marine vertebrates, as a group, tend to be more euryhaline than the invertebrates, with notable exceptions (oyster, blue crab, diatoms, marine algae, and some copepods).

Ideas for using salinity in classroom activities or extracurricular projects are:

1. Comparison of salinities of different bodies or sources of water.

2. Change in salinity of a body of water during a period of time.

3. Change in salinity with depth.

4. Effect of salinity on life processes (growth of plants, movement of amoebas, etc.).

5. Comparison of salinity of blood, protoplasm, and sea water.

6. Determination of toleration limits for plants or animals.

The study of salinity is appropriate to some extent at any level in school. Even very young children are familiar with the fact that salt changes the taste of things and that ocean water tastes salty while lake water does not. Some consideration of the nature of salinity would be significant in developing the concepts of any elementary school child relative to his physical environment.

The sections of the major secondary school science curriculum projects which deal directly with salinity or might be augmented by a consideration of salinity are:

1. CHEM-BOND approach
   a. Chapter 5 -- Liquids and Solids: Condensed Phases of Matter
   b. Chapter 9 -- The Halogens
   c. Chapter 24 -- Some Aspects of Biochemistry: An Application of Chemistry

2. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change

3. CHEM-STUDY
   a. Chapter 1 -- The Science of Chemical Change (properties and change, looking at data, characteristic properties)
   b. Chapter 2 -- Mixtures and Chemical Change
   c. Chapter 13 -- Ions in Solution
   d. Chapter 17 -- Time and Chemical Change
   e. Chapter 18 -- Water

4. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

pH of Sea Water

The pH of an aqueous solution is a measure of the hydrogen ion concentration in the solution. The hydrogen ion concentration in an aqueous solution is expressed as molarity or the number of moles of solute in one liter of solution.[1] For instance, pure water dissociates or ionizes slightly:

$$H_2O \rightleftharpoons H^+ + OH^-$$

---

[1] A mole is the number of grams equal numerically to the atomic or molecular weight of an element.

The concentration of each ion is equal and has been computed as 1.0×10^{-7} moles in one liter at 25°C. So the concentration of each is 0.0000001 M, where M is molarity. For convenience, the exponent or power of 10 of the concentration of the hydrogen ions in a water solution has been designated the pH of the solution. The pH scale is composed of numbers descending and ascending from seven, which is the pH of pure water.

Table 8 shows the relations between molarity, the concentrations of both the hydrogen and hydroxyl ions, and the pH. The concept of pH is based on three statements: (1) "Water is ionized to a slight but definite amount . . ."; (2) "When the ion concentrations are multiplied together, a quantity called the ion-product constant (K_w) results . . ."; and (3) "This constant holds true in any water solution as well as in pure water. . . ." (Nitz, 1961, pp. 216, 217). The ion-product or dissociation constant for any aqueous solution is 1×10^{-14} moles per liter at 25°C. This remains constant in spite of any variation in the concentration of hydrogen and hydroxyl ions. Therefore:

$$K_w = xy$$

TABLE 8

RELATIONS BETWEEN MOLARITY, CONCENTRATIONS OF HYDROGEN AND HYDROXYL IONS, AND pH

Molarity	Conc. H^+	Conc. OH^-	pH
1	1×10^{0}	1×10^{-14}	0
.1	1×10^{-1}	1×10^{-13}	1
.01	1×10^{-2}	1×10^{-12}	2
.001	1×10^{-3}	1×10^{-11}	3
.0001	1×10^{-4}	1×10^{-10}	4
.00001	1×10^{-5}	1×10^{-9}	5
.000001	1×10^{-6}	1×10^{-8}	6
.0000001	1×10^{-7}	1×10^{-7}	7
.00000001	1×10^{-8}	1×10^{-6}	8
.000000001	1×10^{-9}	1×10^{-5}	9
.0000000001	1×10^{-10}	1×10^{-4}	10

where x = concentration of hydrogen ion and y = concentration of hydroxyl ion. The product of x and y must always equal 1×10^{-14} moles per liter. If $x = 1 \times 10^{-1}$, then $y = 1 \times 10^{-13}$ and the pH = 1.

Since the concentrations of the hydrogen and hydroxyl ions are equal in pure water, seven is the pivot for the pH scale. A solution with a pH of seven is defined as neutral on the basis of equality of hydrogen and hydroxyl ions. If a substance liberates hydrogen ions in a water solution, the concentration of hydrogen ions will increase and the pH of the solution will be less than seven. Such a substance is defined as acid. Increasing acidity means decreasing numbers on the pH scale. If a substance liberates hydroxyl ions in an aqueous solution, the concentration of hydrogen ions decreases and the pH of the solution will be more than seven. Such a substance is basic or alkaline.

Mathematically, the pH value is defined as "the logarithm of the reciprocal of the hydrogen ion concentration in the solution" (Nitz, 1961, p. 218).

$$[H^+] = 1.0 \times 10^{-pH} \quad \therefore \quad pH = \log \frac{1}{[H^+]} = - \log [H^+]$$

The pH scale was constructed to afford simplicity of expression and communication.

The concentration of hydrogen ions in water varies considerably (table 9). The pH of surface sea water, in contact with air, usually ranges from 8.1 to 8.4. It depends mainly on the temperature, the salinity, and the partial pressure of carbon dioxide in the atmosphere. The changes in temperature reported in the ocean are slight, and the effect of temperature on the pH of sea water is correspondingly slight. Changes in salinity often mean that acids or bases have been added to or taken from the sea; thus, a change in pH would occur. The partial pressure of carbon dioxide in the atmosphere largely controls the amount of dissolved carbon dioxide in surface waters. Water reacts with carbon dioxide to liberate hydrogen ions in solution.

$$H_2O + CO_2 \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^=$$

If there is an increase in dissolved carbon dioxide in sea water the pH will decrease (i.e., the concentration of hydrogen ions increases).

Photosynthetic plants tend to balance the amount of carbon dioxide through changes in rates of consumption

TABLE 9

VALUES OF pH IN NATURAL WATERS

Water	pH
Crater Lake water (H_2SO_4 present)	1.5
Peat water	4.0-4.5
Rain in open country	5.9
Moorland stream	6.4
Springs in calcareous regions	6.0-6.6
Lake and river water, noncalcareous	6.5-7.0
Lake and river water, calcareous	8.0-8.4
Ponds with weeds (active photosynthesis)	9.6
Sea water on the surface	8.1-8.4
Sea water in pools (active photosynthesis)	8.6
Sea water, depth of 1,000 m, Black Sea (H_2S present)	7.26
Water in alkali soil, Sudan (Na_2SO_3 present)	10.0

Source: Rankama and Sahama, 1950, p. 227.

(respiration). The presence of carbonic acid in the sea, however, is one of the main reasons that the pH of sea water remains relatively constant. Carbonic acid is a weak acid and acts as a buffer in solution. Carbonic acid exists in sea water in a dynamic equilibrium situation:

$$H_2O + CO_2 \rightleftharpoons H^+ + HCO_3^-$$

Synthesis and ionization occur constantly. If acid is added to sea water, the above equilibrium expression is upset and the reaction tends to go to the left. In other words, more H_2O and CO_2 are formed than H^+ and HCO_3^-. Thus, if hydrogen ions are introduced to the sea, the hydrogen ions already there combine with HCO_3^- to form H_2O and CO_2. The result is resistance to a change of pH. This process is called buffer action. Carbonic acid is a buffer, and sea water is a buffer solution. The buffer action is extremely important to the life in the sea because organisms, most of which are sensitive to changes in pH, can utilize carbon dioxide (photosynthesis) and calcium carbonate (shells) without appreciably altering the total pH.

The measurement of pH in sea water is a relatively simple operation. Several methods can be used, all of which are fairly reliable.

Litmus paper and pHydrion paper are available from scientific supply houses. The pHydrion paper is particularly good. Both are readily available and extremely inexpensive.

There are many color discs and indicator solutions available. Table 10 lists the common indicators and their pH range. The use of several indicators will enable the researcher to narrow down the pH of the sample solution. Several limitations accompany the use of color indicators. The pH can never be measured in situ. A sample of the solution must be taken and a specified volume measured. The desirability of measuring in situ, or at least in the field, cannot be over-emphasized. If the sample is taken in the field and brought back to the laboratory for analysis, corrections for temperature and pressure changes must be made, because the ion-product of carbonic acid and other buffers varies with the temperature and pressure (see table 11). The reliability of color indicators in measuring the pH of sea water is reduced also because the presence of neutral salts sometimes affects the color. In addition, the neutral salts increase the ion-product of the indicator, yielding low pH readings. These limitations are not so extensive that color indicators and

TABLE 10

pH COLOR INDICATOR SOLUTIONS

Indicator	Range
Cresol Red - A	0.2 - 1.8
Thymol Blue - A	1.2 - 2.8
Dinitrophenol - B	2.2 - 3.8
Dinitrophenol - A	2.8 - 4.4
Bromphenol Blue - D	3.0 - 4.6
Bromphenol Green - D	4.0 - 5.6
Methyl Red - D	4.4 - 6.0
Bromcresol Purple - D	5.0 - 6.6
Chlorphenol Red - D	5.2 - 6.8
Bromthymol Blue - D	6.0 - 7.6
Phenol Red - D	6.8 - 8.4
Cresol Red - B	7.2 - 8.8
Thymol Purple - D	7.6 - 9.2
Thymol Blue - B	8.0 - 9.6
Cresol Phthalein - D	8.4 - 10.0
Phenol Phthalein - D	8.6 - 10.2
Thymol Phthalein - D	9.2 - 10.6
Alizarin - D	9.8 - 11.4
Tropaeolin - D	11.2 - 12.8
Violet - D	12.0 - 13.6

TABLE 11

TEMPERATURE CORRECTIONS FOR pH MEASUREMENTS[a]

pH_m	S = 18 °/oo Cl = 10 °/oo			S = 27 °/oo Cl = 15 °/oo		
	t^oC 0-10°	t^oC 10-20°	t^oC 20-30°	t^oC 0-10°	t^oC 10-20°	t^oC 20-30°
7.4	0.0087	0.0084	0.0069	0.0088	0.0087	0.0076
7.6	0.0092	0.0092	0.0079	0.0095	0.0096	0.0083
7.8	0.0100	0.0101	0.0089	0.0103	0.0105	0.0090
8.0	0.0108	0.0109	0.0094	0.0110	0.0112	0.0094
8.2	0.0114	0.0115	0.0098	0.0115	0.0117	0.0096
8.4	0.0117	0.0117	0.0099	0.0118	0.0118	0.0098
	S = 35 °/oo Cl = 19.5 °/oo			S = 38 °/oo Cl = 21 °/oo		
7.4	0.0089	0.0087	0.0081	0.0092	0.0089	0.0079
7.6	0.0095	0.0095	0.0091	0.0097	0.0098	0.0088
7.8	0.0104	0.0104	0.0098	0.0106	0.0108	0.0093
8.0	0.0110	0.0109	0.0102	0.0112	0.0114	0.0096
8.2	0.0114	0.0112	0.0103	0.0116	0.0116	0.0098
8.4	0.0116	0.0114	0.0104	0.0118	0.0119	0.0100

Source: Strickland and Parsons, 1960, pp. 176-77.

[a]If pH_a is the original value of the pH of the sample in situ at a temperature t^oC and pH_m is the pH measured in the laboratory at $t_m{}^oC$ (generally greater than t^oC), then:

$$pH_a = pH_m - x(t - t_m)$$

The figures for x are given in the table.

matching discs are useless; they are not as accurate as other methods, but they still give a good approximation of the actual pH.

The most accurate and most expensive method of measurement is the pH meter. These are available from all scientific equipment suppliers. The most accurate are continuous-recording meters. These, however, are not practical nor feasible for field work. Portable meters (battery powered) and pocket-sized meters are quite accurate and easy to handle in the field.

A reference electrode (see section on Eh measurement, p. 156) and a glass electrode are the contacts between the pH meter and the sample to be measured. A general-purpose glass electrode with a pH range from 0 to 11 is the most practical. For measurement of solutions whose pH exceeds 11, a special electrode is needed. The glass electrode is comprised of an acid solution inside a special glass bulb. When the bulb is immersed in a solution, an electric potential difference is developed between the inner and outer solutions which is proportional to the log of the activity of hydrogen ions in the outer solution. The reference electrode completes the circuit with a constant electric potential difference

at 25°C. Most pH meters have special temperature compensators so that the constant electric potential difference developed at the reference electrode is not altered. The electric potential difference at the glass electrode varies with the activity of the hydrogen ions, so that the over-all voltage can be calibrated in terms of pH.

No two glass electrodes show the same electric potential difference in a given solution, so they must be calibrated before each usage against a standard buffer solution of known pH (available from all chemical supply houses). Best results are achieved if two separate buffer solutions are used and the meter is calibrated against each.

The electrodes should be washed between immersions to remove any adsorbed ions. Best results are obtained when the electrodes are given time to come into equilibrium with the sample solution. Prior to equilibrium, much drift may occur. Reliable readings are readily obtainable from sea water in contact with air.

If subsurface water samples are brought to the surface for measurement, contamination occurs when the electrodes are introduced to the system. A steady drift occurs when the water is brought into contact with air for

the first time. Also, temperature changes cause changes in the amounts of dissolved carbon dioxide and hydrogen sulfide, which, in turn, affect the pH. The most reliable results occur when the electrodes go to the environment and the reading is taken with the sample in situ.

For measurement of the pH at the sediment-water interface, the Brooks method (see section on Eh measurement, p. 160) has proved effective. Often, the pH at the interface varies from that of the surface water. If the rate of oxidation and reduction is high, an abundance of hydrogen sulfide at the interface will cause a lowering of the pH to approximately 7.3 or even lower in extreme cases like the Black Sea (see table 9).

Small changes in the pH of sea water may have profound effect on the life in the sea. If the pH of sea water changes, organisms die. The buffering action of weak acids and bases in sea-water solution maintains a relatively constant pH. The pH reflects changes in temperature, salinity, rates of photosynthesis, dissolved carbon dioxide, and other dissolved gases. Most important, the solubility of many substances is controlled by pH. At high pH, calcium carbonate precipitates and is not available for use by organisms.

The pH of many solutions may be readily tested both in the laboratory and in the field. Some ideas for investigation are:

1. Comparison of the pH of sea water, lake water, blood, tap water, etc.
2. Change in the pH of sea water with increasing depth.
3. Change in pH of sea water seasonally and diurnally.
4. Effect of changes in pH on organisms.

Concepts relative to pH are more relevant for secondary school students than elementary school students; however, ideas concerning acids and bases particularly among powders and cleaning fluids used in the home are valuable for young children. The determination of precise pH and its relation to solutions and life processes is most appropriate for secondary school students.

The study of pH is included in the following curriculum projects:

1. CHEM-BOND approach
   a. Chapter 11 -- Aqueous Acids and Bases
   b. Appendix 2 -- Relative Strengths of Acids in Aqueous Solution
2. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change

3. CHEM-STUDY
   a. Chapter 1 -- The Science of Chemical Change
   b. Chapter 2 -- Mixtures and Chemical Change
   c. Chapter 16 -- Acids and Bases
   d. Chapter 17 -- Time and Chemical Change
   e. Chapter 18 -- Water

4. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Light Penetration

Light from the sun is the principal source of energy for the surface of the earth. It provides the heat which is a key factor in oceanic and atmospheric circulation. Plants derive their energy from the sun via photosynthesis. The radiant energy important in ecology and discussed in this division lies mostly within the visible light spectrum (see table 12). Other radiant energy from the sun plays a significant role in ecology but is difficult to measure.

The definition of light is "radiant energy capable of stimulating the eye and causing the sensation of vision. Often extended to radiation near to the visible region of the spectrum, e.g., ultra-violet, infra-red light (deprecated" (Murray, 1952, p. 338).

TABLE 12

WAVELENGTHS OF COLORS

Color	Wavelength (in Angstroms)
Infra-red	24,000 to 760
Red	760 to 650
Orange	650 to 600
Yellow	600 to 550
Green	550 to 500
Blue	500 to 450
Violet	450 to 400
Ultra-violet	400 to 280

The amount of light entering the surface of the sea (incident radiation) depends on the amount of radiation immediately above the surface and the reflectivity of the surface. If high-energy wave action characterizes the surface, its reflectivity is reduced; however, the turbidity is increased, cutting off even more light than would ordinarily be reflected. The basic factor affecting reflection is the angle of incidence of light. Reflection increases as the angle of incidence becomes more acute.

Light penetration into the water, therefore, is highest in tropical seas.

The transmission of light once it has entered sea water has many mitigating factors. Generally, these factors may be categorized as absorbing or scattering. Absorption of light is achieved by water molecules, minute suspended particles, dissolved substances, and marine organisms. The process of absorption of light in sea water is a problem needing further investigation. Light is scattered by water molecules, suspended particles, and organisms (Hedgpeth, 1957, chap. 6). The scattering of light exceeds absorption. Much of the light absorbed has probably been scattered extensively between incidence and absorption. Temperature and the presence of dissolved salts have a slight proportionate effect on absorption.

Table 13 shows a comparison of the transmission of light in different types of water. The designated wavelengths actually represent a spectral band. Oceanic water transmits less light than pure water through a distance of one meter; coastal water transmits less light than oceanic water. The predominant hindrance to light transmission in oceanic water is the presence of suspended particles. In coastal waters, wave action and tidal currents keep an

TABLE 13

PERCENTAGE OF RADIATION OF GIVEN WAVELENGTH TRANSMITTED BY 1 M OF WATER

Type of Water	Wavelength (in Angstroms)						
	460	480	515	530	565	600	660
Pure water	98.5	98.5	98.2	97.9	96.8	88.3	75.9
Oceanic water							
Lowest	96.4	97.5	96.6	96.3	92.9	81.8	. .
Average	91.8	92.7	92.5	91.8	89.8	75.9	. .
Highest	85.1	85.7	86.7	86.9	84.5	71.6	. .
Coastal water							
Lowest	80.0	79.4	82.6	84.5	. .	68.7	62.0
Average	69.7	71.6	75.9	76.4	. .	64.6	53.6
Highest	60.0	63.5	67.1	70.6	. .	61.4	46.7

Source: Sverdrup *et al.*, 1942, p. 86.

abundance of particles in suspension. Rivers emptying into the sea continuously add suspended inorganic and flocculated organic particles. In addition, the presence of "yellow substance" is much greater in coastal waters than in oceanic waters. This yellow substance is a complex of water-soluble yellow pigments probably related to humic acids derived from soils and transported to the sea by rivers and ground water (Sverdrup et al., 1942, p. 88). The chemical composition of the yellow substance is not thoroughly known.

Notice from table 13 that the percentage of light transmitted by all water decreases from the blue (450 to 500) end of the spectrum to the orange (600 to 650) and red (650 to 760) end. The explanation of this may lie in the fact that the wavelengths decrease from blue to red. As a result of the decrease, the smaller wavelengths may be more susceptible to absorption and scattering by water molecules.

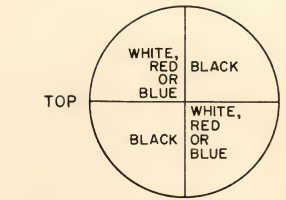
Notice also on the same table that there is little discrimination between blue (450 to 500) and green (500 to 550) light in oceanic water, while appreciably more green than blue is transmitted by coastal waters. Turbid oceanic water resembles coastal waters relative to this discrimina-

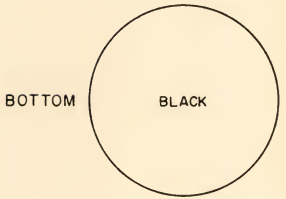
tion. The reason for this has not been satisfactorily explained.

Several methods of measuring light penetration are possible. The most simple device is the Secchi disc. A more sophisticated method is the use of a photometer, which generally measures total absorption and approximately half of the scattering (Hedgpeth, 1957, p. 115). A transparency meter measures the total absorption and total scattering (Hedgpeth, 1957, p. 110).

The Secchi disc (see fig. 5) is a circular metal or wooden plate 30 centimeters in diameter, the upper surface of which is divided into equal quadrants. Two opposing quadrants are painted black; the other two are either white or colored enamel paint. The lower side should be painted black to eliminate reflection from below. If the surface becomes dull, repaint it. A line (polyethylene or nylon) which is graded in meters is attached to the disc at four equidistant points. Suspended below the disc is a weight to facilitate sinking.

Reliable readings can be obtained under the following conditions: (1) cloudless sky, (2) minimal reflection (sun at or near zenith, reader using sunshade), and (3) calm sea. The procedure for reading is as follows:





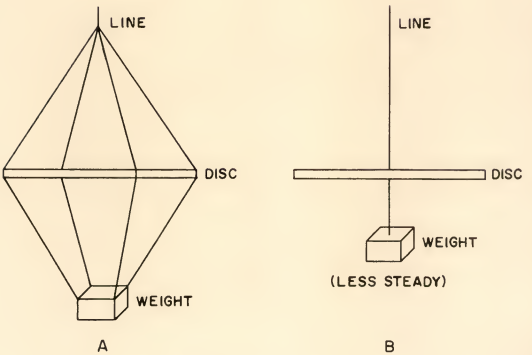


Fig. 5.--Diagram of the Secchi disc.
Source: Flora, 1957, p. 245.

1. Lower disc.
2. Record depth at which disc disappears.
3. Continue lowering, then raise.
4. Record depth at which disc reappears.
5. Depth reading is mean of (2) and (4).

If the surface of the sea is agitated, a glass-bottom pail should be used to see the disc. The error involved due to drifting is:

$$E = \left(\frac{A}{10}\right)^2$$

where E is the error in percentage, A is the angle of inclination due to drift.

The photometer is an instrument based on the photoelectric effect and adapted for use in the marine environment. It consists of a photocell in a waterproof container connected by wire leads to a galvanometer on deck, or at least above water (see fig. 6).

The photocell most often used is a selenium cell.[1] The selenium cell exhibits the photovoltaic effect. In the cell, a selenium layer rests on a metal base. A thin,

---

[1]The photoelectric effect has three aspects: (1) electrons may be liberated from the surface of the material (outer effect), (2) the resistance of the material may be reduced (inner effect), and (3) an electric potential difference may be generated within the material (photovoltaic effect) (Murray, 1952, p. 43).

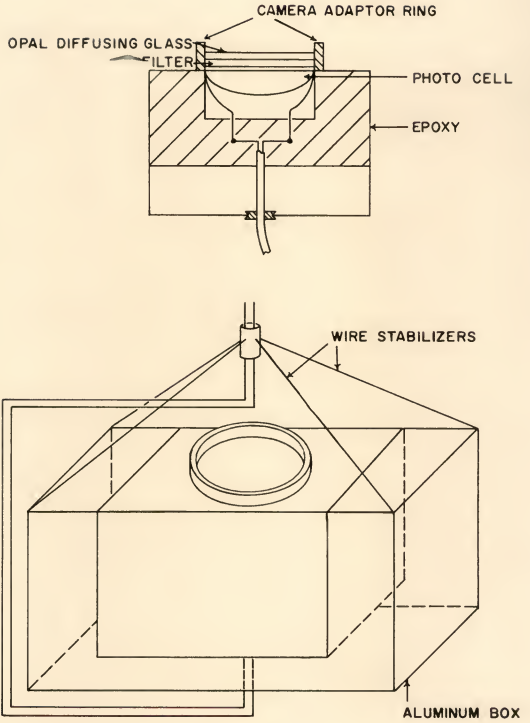


Fig. 6.--Diagram of the photometer, designed by William Delcomyn.

semi-transparent metal film is spread on the selenium layer. The electrons in this cell absorb energy from incident radiation. This energy causes electrons to flow from the metal film to the selenium layer. The flow of electrons generates an electric potential difference at the interface between the metal film and selenium layer (photovoltaic effect). If a cathode and anode are attached to the cell and leads run to a galvanometer, a measure of the radiation intensity is possible (Murray, 1952, chap. 5).

The photocell cannot be allowed to get wet, so it must have a completely waterproof housing. It is possible to seal the entire metal case that contains the photocell. Another way is to cover the photocell and leads with Scotch Caste epoxy, allow the epoxy to harden, and screw the metal case closed; water will enter the case, helping it sink, but the photocell and leads will be waterproof and the photocell stable.

The design illustrated in fig. 6 has several special features: (1) photocell and leads waterproof; (2) photocell stable; (3) filters easily interchangeable; and (4) strain on leads transferred to wire stabilizers.

A variety of designs is possible. The chief

requisites are: (1) stability of cell; (2) waterproof cell; (3) filter between the diffusing glass and the photocell (insure that average obliquity of light passing through filter is independent of angular distribution of incident light) (Atkins et al., 1938, p. 43); and (4) rugged structure to withstand field work.

A transparency meter (fig. 7) is a more complicated device than the photometer. It consists of a light source of known intensity, a mirror at a distance of one meter from the light source, and a photocell adjacent to the light source. A galvanometer measures the electric potential difference generated by the photocell. This measurement will be a function of total absorption and total scattering.

Fig. 8 is a transparency meter which measures total scattering and some absorption. One photocell is placed at right angles to the light source and is offset at least one foot from the direct beam of the light source. The other is opposite the light source at a distance of one meter. This transparency meter will measure the Tyndall effect.

Of particular interest in physical oceanography is the rate at which downward radiation decreases with depth

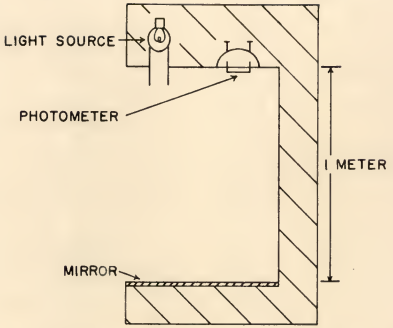


Fig. 7.--Transparency meter designed to measure total scattering and total absorption.

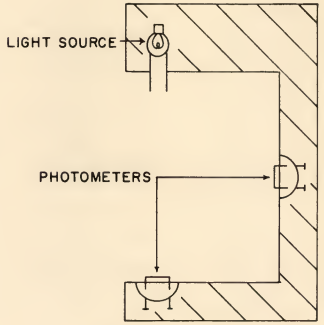


Fig. 8.--Transparency meter designed to measure total scattering and some absorption.

(measured per meter). The extinction coefficient of light is a measure of both absorption and scattering. For the Secchi disc, the extinction coefficient (K) is found by:

$$K = \frac{1.7}{D}$$

where D = depth at which disc disappears. For photometric determinations, the coefficient is found by:

$$K = 2.30 \ (\log I_{w,z} - \log I_{w(z+1)})$$

where I_w = radiation intensity for a given range of wavelengths and z = depth in meters (Sverdrup et al., 1942, p. 82).

Although the extinction coefficient is reported and widely referred to in the literature, it is seriously limited. The depth at which a Secchi disc disappears depends upon the eyesight of the researcher. The radiation intensity depends on the capacitance of the photometer and the variability of the resistance in the wire leads. The correlation between extinction coefficients reported by one researcher may be inconsistent with those reported by a researcher using different equipment. It is suggested by the author that photometric equipment be standardized with a Weston light meter so that the readings can be

readily correlated with foot-candles, the standard measure of light intensity in physics. Another useful reading is the percentage of light penetration measured by the photometric method. The spectral band of the filter used should be reported.

The color of the sea varies from blue to green to reddish-brown or brown. The blue color is the result of light scattered by water molecules and minute suspended particles which are smaller than the shortest visible light wavelength. Essentially, these are the same causes of blue color in the sky. Green color, it has been suggested, is due to the presence of "yellow substance" (see p. 125), and possibly some fluorescence. Any reddish or brownish color is generally thought to be associated with algae or flocculated organic material. This rusty color is most common in coastal waters in lagoons or estuaries (Sverdrup et al., 1942, p. 89). In tropical near-shore waters, a milky color is often observed when winds exceed 10 to 15 knots. The wind generates waves which stir up calcareous oozes (often highly foraminiferal) which have accumulated in bays or other ordinarily quiet waters.

The ocean is divided into the photic and aphotic zones. The photic zone is that part of the ocean which is

penetrated by daylight. The division between these zones fluctuates considerably. Photosynthetic marine plants must either migrate along with the fluctuations, go into a period of dormancy, or undergo a proportional fluctuation in productivity. Since photosynthetic plants are the base of the "food chain" in the ocean, light can be considered a controlling factor in the "food chain."

Some species of marine plants have optimum light intensities for carrying on photosynthesis. To compensate for changes in light penetration, these organisms migrate vertically. The organisms dependent upon them will migrate also.

Diatoms function efficiently in a wide range of light intensity. As a result, they have a wide distribution in the oceans and are not subject to vertical migrations. The upwelling of nutrient-rich waters is more significant than light fluctuation as a population control of diatoms within the photic zone.

The depth beyond which photosynthetic plants are not found is called the compensation depth. There is enough light for photosynthesis, but there is a balance between the oxygen produced and the oxygen utilized. Because of this balance, there is a lack of dissolved oxygen

in the water, and marine animals cannot survive. Here, light is the major control of population, and predation is minimal. This region is often referred to as the intermediate zone or intermediate waters (see also the section below on dissolved oxygen).

Below the compensation depth, the abundance of life is reduced. The aphotic zone is characterized by a reduced number of species. However, the populations of these few species are large because there is less competition for food.

The measurement of light penetration in the sea can easily become a part of scientific activities of students from the elementary school through secondary school. The importance of light and particularly light from the sun can be understood readily by very young students. Building and operating a Secchi disc is within the realm of capabilities of elementary school students. The extent to which other methods are used will depend primarily on the interest and capabilities of interested students. The study of light and oceans are two subjects often included in general science courses. Oceans are an important aspect of any earth science course. The study of the relationships between light and life is integral to an under-

standing of biology. Most physics courses include a study of the behavior of light. The consideration of light penetration in the sea appears to be appropriate at diverse points in the over-all science curriculum.

Some particular ideas for inquiry are:

1. Light penetration at various depths for a locality.
2. Comparison of light penetration at different localities.
3. Penetration of light of different wave lengths.
4. Correlation of light penetration with the type and abundance of life.
5. Light penetration in different bodies of water (river, pond, sea).
6. Explanation of quantitative results as an expression of a concept of causality.
7. Change in light penetration at given depths at high tide and low tide.
8. Change in light penetration at given depths at different times of the year.
9. Change in light penetration at a given depth from sunrise to sunset.

Reference to light and oceans may be found in the following:

1. BSCS (unifying themes) (particularly applicable in Green Form)
   a. The complementarity of organism and environment

b. Regulation and homeostasis: preservation of life in the face of change
c. Science as inquiry

2. PSSC
   a. Part II -- Optics and Waves
   b. Part IV -- Electricity and Atomic Structure

3. CHEM-STUDY
   a. Chapter 4 -- Electricity and Matter
   b. Chapter 5 -- Charge Separations and Energy
   c. Chapter 6 -- Electrical Nature of Matter
   d. Chapter 11 -- Metals
   e. Chapter 18 -- Water

4. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Dissolved Oxygen

Free oxygen in the earth's atmosphere is a prerequisite for life as we know it. Oxygen constitutes about 21 per cent of the total gases in the atmosphere (Sverdrup et al., 1942, p. 189). Oxygen dissolved in sea water is necessary for the respiration of marine organisms and is present throughout sea water, although in varying amounts. In the seas, the amount of dissolved oxygen varies from about 1 $^{o}/_{oo}$ ($^{ml}/l$) to about 9 $^{o}/_{oo}$ ($^{ml}/l$). The maximum amount of dissolved oxygen that sea water can

hold depends on the temperature and salinity (see table 14).

The source of dissolved oxygen in the oceans is principally by absorption from air at the surface or from plants as a by-product of photosynthesis. Gases in the air and dissolved in sea water constantly move from one medium to the other. Oxygen is no exception. The saturation values given in table 14 are equilibrium values. Upwelling of oxygen-deficient deep water, the variability of rates of photosynthesis, and changes in solubility at different temperatures cause imbalance of the ideal equilibrium, in which case oxygen may be absorbed or given off by sea water. In addition, exchange between air and sea is a function of wave action. Large waves which crest and break offer more surface area per given volume through which exchange can occur than swells or calm seas.

Laboratory experiments in water with 1 to 20 per cent sodium chloride have shown that molecular diffusion of oxygen through such a solution is negligible (Hedgpeth, 1957, p. 196). Distribution of oxygen in sea water is not predominantly by diffusion. Biological activity has a major effect on the amount and distribution of oxygen. The distribution, in turn, of organisms and oxygen absorbed

TABLE 14

SATURATION VALUES OF O_2 IN SEA WATER FROM NORMAL DRY ATMOSPHERE

Temperature (°C) \ Chlorinity (°/oo) / Salinity (°/oo)	15 27.11	16 28.91	17 30.72	18 32.52	19 34.33	20 36.11
-2	9.01	8.89	8.76	8.64	8.52	8.39
0	8.55	8.43	8.32	8.20	8.08	7.97
5	7.56	7.46	7.36	7.26	7.16	7.07
10	6.77	6.69	6.60	6.52	6.44	6.35
15	6.14	6.07	6.00	5.93	5.86	5.79
20	5.63	5.56	5.50	5.44	5.38	5.31
25	5.17	5.12	5.06	5.00	4.95	4.86
30	4.74	4.68	4.63	4.58	4.52	4.46

Source: Sverdrup et al., 1942, p. 188.

from the air is a function of circulation of ocean water (see section on currents above). Interrelated with currents and biological activity are temperature and salinity (see table 14). The computed amount of dissolved oxygen is dependent upon a complex of interrelated processes and properties, as is everything in the marine environment. In general, the amount of dissolved oxygen decreases with both increased temperature and increased salinity; however, a large change in salinity has less effect on the amount of dissolved oxygen than a large change in temperature (see table 14). Whether this is due to a reduction in the solubility of oxygen in sea water with increased temperature, due to a reduction in the abundance of planktonic organisms with increased temperature, or a combination of the two (most likely) is not clear from the literature. It has also been reported that the amount of dissolved oxygen in sea water is related to differences in the partial pressure of oxygen which is dependent in part on the temperature and biological activity. The fact remains that polar surface waters have higher amounts of dissolved oxygen than tropical surface waters (Hedgpeth, 1957, p. 189).

Water from the lower neritic zone is generally

colder than surface water because of solar moderation. Also, this water has fewer photosynthetic organisms because light penetration is limited, accounting for a deficiency in dissolved oxygen. When upwelling of sea water formerly in this zone occurs, water deficient in oxygen reaches the surface.[1] In some cases, currents cause swift mixing of the water distributing dissolved oxygen. Sometimes absorption from the atmosphere is swift, if the air and water are cold enough. Occasionally, neither occurs and many organisms accustomed to the high oxygen content of normal surface water suffocate. This circumstance is part of the cause of the observed phenomenon often referred to as "red tide."

Density is another factor involved in the distribution of dissolved oxygen. "The ease of vertical mixing is inversely related to the stability of the water column, which is nearly proportional to the vertical rate of change of density" (Hedgpeth, 1957, p. 198). Water tends to flow from areas of high density to areas of low density, producing vertical flow in the sea and distribution of oxygen.

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[1]Upwelling is a phenomenon occurring in coastal waters. When wind pushes water away from the coast, subsurface water replaces it (Sverdrup et al., 1942, p. 501).

In summary, the amount and distribution of dissolved oxygen in the ocean is determined by: (1) density, (2) salinity, (3) temperature, (4) biological activity, (5) currents, (6) eddy diffusion, and (7) upwelling.

With modifications, the Winkler method of determining dissolved oxygen is generally accepted as the most reliable relative to sea water (Strickland and Parsons, 1960, pp. 23-28).

Special Apparatus

300-ml biological oxygen demand (B.O.D.) bottles

500-ml pipette (automatic "Lowy" type recommended)

10-ml burette graded in 0.05-ml units or less (automatic zero adjuster recommended)

125-ml conical flasks

stirring bar

Special Reagents

1. Manganous sulfate -- Dissolve 480 g $MnSO_4 \cdot 4H_2O$ (400 g $MnSO_4 \cdot 2H_2O$ or 365 g $MnSO_4 \cdot H_2O$) in distilled water and fill to one liter.

2. Alkaline iodide -- Dissolve 500 g NaOH or 700 g KOH in 500 ml distilled water; dissolve 150 g KI in 200 ml

distilled water; mix; dilute to one liter with distilled water.

3. Approximately 0.0085 N thiosulfate -- dissolve 2.2 g $Na_2S_2O_3 \cdot 5H_2O$ (sodium thiosulfate) and 0.1 g Na_2CO_3 in one liter distilled water.

4. Starch indicator -- Suspend 2 g of soluble starch in 300 to 400 ml of water; add 20 per cent NaOH solution with vigorous stirring until the solution clears; let the solution stand for two hours; add concentrated HCl until the solution is just acid to litmus paper; add 2 ml of glacial acetic acid; dilute to one liter with distilled water.[1]

5. 0.0100 N iodate -- Dry KH (IO_3) (potassium bi-iodate) at 105°C for one hour; cool; weigh out 0.3250 g; dissolve in 200 to 300 ml of water, warming the solution slightly; cool; transfer to one-liter measuring flask and dilute to one-liter mark exactly with distilled water.

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[1] Starch Indicator

1. Prepare an emulsion of 5 to 6 g of potato in a beaker with a little distilled water.

2. Pour emulsion into one liter boiling water.

3. Allow to boil a few minutes.

4. Let settle overnight.

Use the clearer solution at the top as an indicator. The indicator may be preserved by adding a few drops of toluene or 1.25 g salicylic acid per one liter of solution.

Sampling Procedure

1. Rinse B.O.D. bottles in water to be sampled.

2. Fill bottles in place or, if the sample was obtained at depth, siphon water into B.O.D. bottle with minimum of turbulence (keep rubber siphon below surface of water).

3. Let water overflow top of B.O.D. bottle to insure complete displacement of air.

4. Stopper or cap at once.

If there is a large temperature difference between the sample and the air, analyzing procedure should not start immediately. The B.O.D. bottle, when filled, should be kept in darkness (in a box,or wrap aluminum foil around the bottle) so that photosynthesis does not proceed in the sample, altering the oxygen content.

Procedure for Determining Dissolved Oxygen

Steps 1 and 2 must be done in the field immediately after obtaining the sample. Allow no air bubbles at any step.

1. Remove stopper from B.O.D. bottle; add 1.0 ml $MnSO_4 \cdot NH_2O$ solution with pipette, followed at once by 1.0 ml alkaline iodide solution (place pipette just below surface of water); recap the B.O.D. bottle immediately and mix by shaking until the precipitate (manganous-manganic hydroxide) is evenly dispersed.

2. Allow the precipitate to settle for two to five minutes; shake again; sample can be stored at this stage for several days or more.

3. (Ready to begin titration.) Add 1.0 ml of concentrated H_2SO_4, recap, and mix until precipitate dissolves.

4. Transfer 50.0 ml of sample solution to conical flask by means of a pipette.

5. Titrate at once with thiosulfate solution until a pale straw color remains; add 5 ml of starch indicator; conclude titration.

ml O_2(NTP) per l. = 0.1006 x f x V x 11.20

where V = volume of titration in ml, f = special factor.

Determination of f

1. Fill 300-ml B.O.D. bottle with sea water.

2. Add 1.0 ml concentrated H_2SO_4.

3. Add 1.0 ml alkaline iodide solution.

4. Mix thoroughly.

5. Add 1.0 ml $MnSO_4 \cdot NH_2O$.

6. Mix again.

7. Withdraw 50 ml into each of five titration flasks.

8. Add 5.00 ml of 0.0100N iodate solution.

9. Allow iodine liberation to continue for more than two but less than five minutes.

10. Titrate the iodine with the thiosulfate solution.

$$f = \frac{5.00}{v}$$

where v = titration volume in ml (use mean v from at least three titrations).

The final reading of dissolved oxygen is then usually given in ml per liter or °/oo (parts per thousand).

The amidol colorimetric method does not yield a quantitative oxygen content, but is useful if a qualitative comparison is adequate. The presence of oxygen is indicated by a brown color, which darkens with increasing oxygen content. The procedure follows:

1. Fill a B.O.D. bottle with the water to be tested (follow sampling procedure described in Winkler method).
2. Add three grams of fine granular sodium citrate (allow no air bubbles).
3. Scatter a small arbitrary amount of powdered lauryl sulfate onto the surface so that a film covers the surface.
4. Add one gram amidol (diaminophenol hydrochloride) onto the film.
5. Close B.O.D. bottle tightly and turn upside down, to facilitate mixing.
6. Allow to stand in shade or dark for 30 minutes.
7. Check the color.

This method allows for qualitative comparison of the oxygen

content of different water samples. Only the relative oxygen content can be estimated.

> The exchange of chemical elements between sea-water and the biomass is a cyclic process. The cycle may be broken down into two phases, synthesis and regeneration. Elements are withdrawn from the water during the synthetic phase by photosynthesis in the proportions required for the growth of the primary producers, which are predominantly the phytoplankton. These elements are ultimately returned to the water in the regenerative phase as the decomposition products and excretions of both the primary producers and the subsequent members of the food chain which prey upon them, including the micro-organisms which complete the decomposition of organic debris.
>
> Oxygen occupies a unique position in the biochemical cycle because this element is set free in the course of photosynthesis. The concentration of oxygen consequently increases in the water when synthesis takes place and this oxygen becomes quantitatively available for the subsequent oxidation of the products of this synthesis [Hill, 1963, p. 27].

If the role of oxygen in the biochemical cycle of the sea is traced, its importance is self-evident. Free oxygen is one of the products of photosynthesis. Once emitted, oxygen is dissolved in the sea water. As a dissolved gas, it is essential for the respiration of marine fauna (other than mammals). It also oxidizes dissolved waste products and suspended organic material. Much of the dissolved oxygen remains unused and is distributed throughout the sea. As the oxygen is circulated, it con-

tinuously oxidizes organic matter and combines with other elements in the decomposition process. Below the depth of light penetration (photic zone), the supply of oxygen is solely from water circulation. This supply occasionally is depleted if the content of organic material is high, in which case anaerobic conditions will prevail and oxidation continues by means of bacteria rather than free oxygen. Eventually, the ever-circulating ocean waters return the nutrients (oxidized organic material) to surface waters, where they are once again synthesized by organisms.

In general, synthetic processes utilizing nutrients account for the production and addition of dissolved free oxygen to the sea in the photic zone. Regenerative processes in deep water convert the free oxygen and other elements to nutrients such as carbonate, phosphate, and nitrate ions. Synthetic and regenerative processes occur at all depths in the ocean, but one always predominates at a given depth or in a given volume.

All the animals of the sea need oxygen. The mammals must obtain their oxygen from the air. However, the other marine animals take it directly from the sea as a dissolved gas.

The protozoans represented predominantly by fora-

minifera, radiolarians, and the flagellates respire by diffusion directly through the cell membrane between the protoplasm and the surrounding sea water. For other animals, oxygen is diffused either through the body surface or through specialized gill structures.

The measurement of dissolved oxygen in sea water is an appropriate activity for advanced biology or chemistry students in secondary school or for talented students involved in special projects. The techniques required for the determination of oxygen content are too sophisticated for most students. Many interested students may find it challenging, however.

All studies or projects dealing with the measurement of dissolved oxygen should be prefaced by thorough reading and understanding of the difficulties involved in recovering uncontaminated or undisturbed water samples and the limitations of the measurement techniques. The final data are grossly limited in most cases and must be approached as a general indication of the actual oxygen content. In this case, the quantitative results should be considered either approximate indications or facts under a flexible definition of what a fact is.

Many interesting studies are possible:

1. Analysis of the problems in recovery of samples.

2. Analysis of problems in quantitative techniques.

3. Measurement of dissolved oxygen at a particular depth at a particular location periodically (diurnally, monthly, seasonally).

4. Measurement of dissolved oxygen at a given depth in different localities.

5. Comparison between dissolved oxygen in surface waters and at depth.

6. Comparison between dissolved oxygen in standing water and in well-circulated water.

7. Comparison between dissolved oxygen content and phytoplankton population.

Dealing with dissolved oxygen in sea water can be a valuable supplement to the curriculum specifically:

1. CHEM-BOND
   a. Chapter 4 -- The Gas Phase: Kinetic Theory
   b. Chapter 10 -- Solubility Equilibria
   c. Chapter 16 -- Molecules in the Gas Phase

2. BSCS (unifying themes)
   a. The complementarity of organism and environment
   b. Regulation and homeostasis: preservation of life in the face of change
   c. Science as inquiry

3. PSSC
   a. Chapter 9 -- The Nature of a Gas
   b. Chapter 10 -- Measurement

4. CHEM-STUDY
   a. Chapter 1 -- The Science of Chemical Change
   b. Chapter 2 -- Mixtures and Chemical Change
   c. Chapter 3 -- Gases, Molecules, and Masses
   d. Chapter 15 -- Concentration and Chemical Change
   e. Chapter 17 -- Time and Chemical Change
   f. Chapter 18 -- Water

5. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

Oxidation-Reduction in Bottom Sediment

All oxidation-reduction reactions are chemical reactions involving a shift of electrons from one atom to another. Oxidation never occurs without reduction, and reduction never occurs without oxidation for a system in equilibrium. Oxidation is the term used to describe any chemical change in which an atom increases its oxidation number. Reduction is any chemical change in which an atom decreases its oxidation number (oxidation number approximately the same as valence). Consider the reaction:

$$O_2 + 2H_2 \longrightarrow 2H_2O$$

In the oxygen molecule (O_2), each oxygen atom has two

electrons in its inner orbit and six electrons in its outer orbit (all electrons have a -1 charge). In the hydrogen molecule (H_2), each hydrogen atom has one electron in its orbit. When the above chemical reaction occurs, the electrons in each hydrogen molecule shift to the outer orbit of each oxygen atom. Thus, each hydrogen atom loses an electron, leaving the atom with a net charge of (+1) (assuming all molecules have a net charge of 0 or are neutral) and each oxygen atom gains two electrons, achieving a net charge of (-2). Since the electrical charge of the oxygen atom has been reduced from 0 to -2, reduction has occurred to the oxygen. Since the charge of the hydrogen atom has increased from 0 to +1, oxidation has occurred to the hydrogen (see section on pH for relation to hydrogen ion concentration).

The charge on an atom or ion is often used synonymously with the oxidation number. This is not entirely correct. The oxidation number is defined as the charge which an atom appears to have. There are arbitrary rules for determining the oxidation numbers of atoms (Sienko and Plane, 1961, pp. 107-9):

1. In the free elements, each atom has an oxidation number of 0, no matter how complicated the molecule is.

2. In simple ions (ions which contain one atom), the oxidation number is equal to the charge on the ion.

3. In most compounds containing oxygen, the oxidation number of each oxygen atom is -2.

4. In most compounds containing hydrogen, the oxidation number of hydrogen is +1.

5. All oxidation numbers must be consistent with the conservation of charge. . . .
   a. For neutral molecules, the oxidation numbers of all the atoms must add up to zero;
   b. For complex ions (charged particles which contain more than one atom), the oxidation number of all the atoms must add up to the charge on the ion.

Following are further examples of oxidation-reduction reactions (the number represent the oxidation numbers for each atom):

1. $\underset{0}{O_2} + \underset{0}{2H_2} \longrightarrow \underset{+1-2}{2H_2O}$

   (The oxygen has been reduced; the hydrogen has been oxidized.)

2. $\underset{0}{Cl_2} + \underset{0}{2Na} \longrightarrow \underset{+1-1}{2NaCl}$

   (The chlorine has been reduced; the sodium has been oxidized.)

3. $\underset{0}{2Mg} + \underset{0}{O_2} \longrightarrow \underset{+2-2}{2MgO}$

   (The magnesium has been oxidized; the oxygen has been reduced.)

4. $\underset{0}{Mg} + \underset{0}{Cl_2} \longrightarrow \underset{+2-1}{MgCl_2}$

(The magnesium has been oxidized; the chlorine has been reduced.)

5. $\underset{+3}{2Fe^{+3}} + \underset{+1-2}{H_2S} \longrightarrow \underset{+2}{2Fe^{++}} + \underset{0}{S} + \underset{+1}{2H^+}$

(The ferric ion is reduced to the ferrous ion; sulfur is oxidized.)

Notice from the examples that oxygen need not be present in the reaction for oxidation and reduction to occur. The concept of oxidation-reduction pertains to electron shifts between atoms in chemical reactions.

The oxidation-reduction (redox) in bottom sediments of the sea has a far-reaching effect on the chemical reactions that occur on the bottom, the chemical composition of bottom sediments, changes that result from sedimentary processes such as compaction or decay, and the biological population (biomass). Very little is known specifically about redox in sediments. Since redox is a dynamic process occurring in the ever-changing environment of the sea bottom (benthos), any measurement of redox will be subject to pronounced fluctuation.

Redox is measured on the Eh scale, which is calibrated in millivolts and has limits determined by the elements. Zero on the scale means that equilibrium has

been established at that precise moment and spot. It is a quantitative expression of the oxidizing or reducing intensity of a system. The intensity reflects the action of the moment. This changes with time and with position. Intensity is not to be confused with capacity, which is a computed and fixed quantity. The intensity is highly variable. Eh is "the electron escaping tendency of a reversible oxidation-reduction system" (ZoBell, 1946b, p. 477).

Eh or redox potential is measured with an electrode pair consisting of a chemically inert electrode (usually platinum) and a reference electrode (saturated calomel) connected by leads to a standard pH meter. The role of the calomel is to supply a known electric potential difference and to make an electric connection with the system to be measured. The inert electrode acts as an electron donor or acceptor to the ions in the measured solution. If the reading is more than seven, the electrode is the donor and the solution is reducing; if the reading is less than seven, the electrode is the acceptor and the solution is oxidizing. The conversion of the pH calibration to the Eh scale is:

(7 - reading on pH scale) 60.0 = number of millivolts

If the reading is ten, then the Eh is -180 mv. If the reading is four, then the Eh is +180 mv.

The best inert electrode is the platinum thimble-type which has a large surface area. This is both a good donor and a good acceptor. In addition, it is easy to clean mechanically by rubbing with fine emery paper. Its most serious drawback is that it will yield erratic readings in a solution containing divalent sulfur (strongly reducing environment).

The chief requirement of the reference electrode is to provide a constant electric potential difference at a given temperature. A saturated calomel is most commonly used. This electrode has mercury in contact with mercurous chloride, which in turn is in contact with a saturated solution of potassium chloride. The electric connection with the solution to be measured is made by the diffusion of the potassium chloride, which ionizes readily in solution, through a hole in the electrode with a fiber screen or by a tightly fitted sleeve covering a hole at the bottom of the electrode (see fig. 9).

Eh measurements depend upon: (1) the assumption that dissolved atoms and ions are in internal equilibrium which does not hold for sulfate or bisulfate ions or

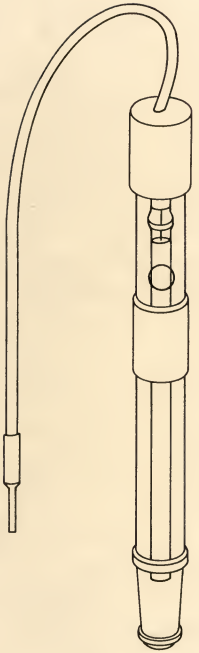

Fig. 9.--Reference electrode (calomel).

dissolved oxygen, and (2) the platinum electrode must function as an inert electrode, which does not hold for a strongly reducing environment (Garrels, 1960, p. 68).

It has previously been mentioned that readings vary with both time and position. In an isolated, controlled laboratory environment, readings cannot be duplicated within 5 mv reliably. Field measurements may vary as much as $\pm$ 20 mv in the same spot in subsequent readings! Are readings as inaccurate as these useful? They are relatively useful. The researcher must accept the limitations of his equipment and treat the data accordingly. A reading of -390 mv ($\pm$20 mv) indicates a highly reducing environment. If in subsequent readings the least reducing is -350 mv, then the researcher has substantial evidence supporting description of the environment as reducing. A series of readings indicating a range of intensity over a period of time is most desirable.

Continuous recording meters are available commercially but are practical in the field only when a source of electrical power is available (rarely). Battery-powered portable meters are available (about $250) which will measure Eh, pH, and Cl^- by switching electrodes and

following standardization procedures. The portable meters will provide useful generalized readings.

One who reports, "The Eh of Station N is . . . " reflects a naive concept of his data. "The Eh of Station N seems to vary from x mv to y mv on July 5 at approximately 10:00 A.M. in a sea-water solution of temperature 28° C" is a more reasonable reporting procedure.

When an electrode is introduced into a system, air accompanies it. This means that the accuracy of the readings is impaired. Bringing the environment to the electrodes or to the laboratory is virtually impossible. The best results are obtained by introducing the electrodes directly to the system. This is possible with long, well-insulated leads. The author has made useful readings using the Brooks method for obtaining bottom sediment (H. K. Brooks, University of Florida, personal communication). The Brooks method is:

1. Empty a beer can.
2. Remove the top of the can.
3. With a center punch, put a hole in the other end of the can.
4. Obtain a cork that will fit the hole.
5. Sink the can into the mud open end first.

6. Insert the cork.

7. Remove the can; the sample will remain in the can because of the vacuum thus created.

8. Insert the electrodes from the bottom slowly, noting the variation as nearly as possible until the vacuum is released.

The last values before the vacuum is released will be the closest indication of the Eh of the interface between the sea water and the bottom sediments. Since there is a vacuum in the can, no air penetrates. Pollution due to the introduction of the electrodes is minimized because they pass through several inches of sediment of similar Eh before reaching the interface. The most serious limitation is the lack of time for the electrodes to reach approximate equilibrium with the system.

In general, positive values characterize bottom sediments that are well oxygenated, have coarse particles, and are devoid of organic matter. Negative values indicate a bottom rich in organic matter and having fine sediment.

An oxidizing environment is found most often in areas where currents are active and the bottom sediment is fairly coarse sand, pebbles, or broken shells. On this type of bottom, organic material is swept away so that

bottom-dwelling (benthonic) organisms have no food source. If there is an outcrop of rocks, pilings, or other relatively stable base in an oxidizing environment, organisms that attach (barnacles, mussels, limpets, coral) and their predators (starfish) may be abundant. These attached (sessile) organisms are filter-feeders and depend upon the currents to bring food (algae, foraminifera, diatoms, radiolarians) to them.

Reducing environments are characterized by poor water circulation, fine sediment, and an abundance of decomposing organic material. Bacteria decompose the organic matter, producing carbon, nitrogen, and hydrogen sulfide. Occasionally, a reducing environment is found in areas of good circulation and coarse sediment. The rate of organic productivity exceeding the rate of decay is generally the reason for this condition.

A reducing environment generally has an abundant benthonic fauna consisting of pelecypods, foraminifera, annelids, and crustaceans. If the environment reaches an Eh in excess of about -450 mv, most of the above organisms decline and anaerobic bacteria become more abundant.

The reducing environment is of particular interest economically because hydrocarbons are formed diagenetic-

ally on the bottom and in recently buried marine sediments. Although the specific formation of oil is yet to be discovered, a reducing environment and the organisms found in a reducing environment are generally thought to be intimately associated with the formation of oil (Levorsen, 1958, chap. 11).

Most marine geologists and biologists agree that oxidation-reduction is an extremely important environmental variable. The extent of its importance in determining the composition of bottom sediments and its role in limiting the biomass remains relatively unknown. Much more investigation is needed; new techniques for obtaining more reliable data are needed.

The most serious problem in the discussion and reporting of Eh measurements in the natural environment has been a lack of understanding by researchers of the nature of oxidation-reduction reactions. In much of the literature, redox potential (Eh) is used synonymously with the presence of dissolved oxygen. They are separate although sometimes related. The presence of oxygen is a special case of redox. Redox refers to the exchange of electrons, which may or may not involve oxygen. The correct usage of the term "reducing environment" is an

environment in which electrons flow to the inert electrode. An "oxidizing environment" is one in which electrons flow away from the electrode. Relative to a reducing environment, little is known about the source of the electrons. Much research is needed in this area.

Although the evidence is meager, the author suspects that in a reducing environment, the decomposing organic matter is oxidized, or oxygen in radicals ($SO_4^{=}$, NO_2^{-}, etc.) is oxidized to the oxygen molecule, thence taken up immediately by respiring organisms (foraminifera and annelids) while sulfur, nitrogen, phosphorus, and iron are reduced. The negative millivolt readings on the pH meter would reflect electrons flowing from the latter elements because they are not used by the organisms.

Since so little information is available concerning redox in the natural environment, any projects in this area would be worthwhile. Some specific problems needing investigation are:

1. Record of the range of redox potential in a given spot for an extended period (2 to 12 hours).
2. Eh of different types of bottom sediment.
3. Change in Eh relative to penetration in sediment.

4. Eh in sediment overlain by well-circulated water compared to Eh in sediment overlain by stagnant water.

5. Comparison of Eh of lacustrine, fluvial, and marine sediments.

6. Correlation of Eh of sediment with biomass.

Oxidation-reduction ratios involve some sophisticated concepts and techniques. As a result, the author feels that, under ordinary circumstances, a consideration of redox is inappropriate at the elementary school level.

At the secondary school level, however, redox potential is an important aspect of chemistry, biology, and geology. It involves concepts which have provided stumbling blocks for high school chemistry students for many years. Some field work investigating redox might be a valuable supplement to laboratory work. Traditionally, chemistry courses neglect the fact that chemical changes occur continuously in nature. This fact is often a thrilling realization to beginning students and can be an important motivating factor, particularly for the many students who have trouble relating "test-tube" reactions with chemical changes in the natural world.

Science curriculum projects which could be supplemented by redox studies are:

1. CHEM-BOND
   a. Chapter 3 -- Chemical Reactions
   b. Chapter 9 -- Equilibrium in Chemical Reactions
   c. Chapter 12 -- Oxidation-Reduction Reactions

2. BSCS (unifying themes)
   The complementarity of organism and environment

3. CHEM-STUDY
   a. Chapter 1 -- The Science of Chemical Change
   b. Chapter 2 -- Mixtures and Chemical Change
   c. Chapter 13 -- Ions in Solution
   d. Chapter 14 -- Free Energy and Electron Transfer
   e. Chapter 17 -- Time and Chemical Change
   f. Chapter 18 -- Water

4. ESCP
   a. Chapter 9 -- The Hydrosphere
   b. Chapter 13 -- Ocean Basins and Their Sediments

CHAPTER IV

A RESEARCH MODEL

The Seasonal Fluctuation of the Population of Foraminifera at Seahorse Key, Florida, and Certain Ecologic Factors

Location

Seahorse Key is one of the Cedar Keys which are located 15 miles south of the Suwannee River and 3 miles south of the town of Cedar Key on the west coast of Florida (see fig. 10). U.S. Geological Survey topographic maps of the following Florida quadrangles show Seahorse Key and the surrounding area: Suwannee (1954), East Pass (1954), Chiefland S.W. (1954), Cedar Key (1955), Sumner (1955), and Seahorse Key (1955).

General Physical Geography

The Cedar Keys and vicinity are characterized by brackish water marshes, hammocks, and occasional sand hills. The topography is generally a regular limestone plain sloping gently seaward. The elevation drops from

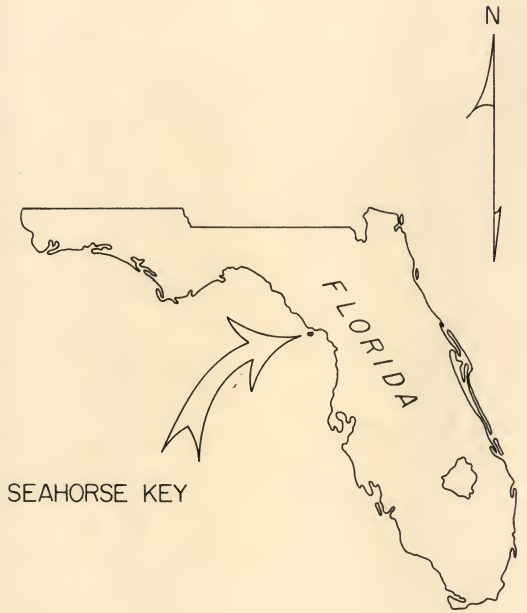

Fig. 10.--Map of Florida.

an average of 25 feet in the northeast section of the Chiefland S.W. quadrangle at a rate of one foot per mile to the Gulf of Mexico. Any variation in elevation is due to the presence of scattered sand hills, sinkholes, and Indian shell mounds. The area has been denuded and groundwater solution is now the dominant agent of erosion.

The principal marsh areas are Gulf Hammock, just southeast of the Cedar Keys, and Black Point Swamp, just north of the Cedar Keys.

The Cedar Keys themselves are a series of islands most of which are mangrove islands, sand hills, shell mounds, or complexes of all three. Scattered among these islands are abundant oyster bars and very shallow, shifting banks. Tidal channels weave between the banks, bars, and islands.

Seahorse Key is underlain by the Ocala limestone of Upper Eocene age -- exactly what member of the Ocala limestone is uncertain. It may be the Crystal River member (Vernon, 1951, pl. 1) or possibly the Williston member. There is a major unconformity at the surface of the limestone upon which Pleistocene sands have been deposited (Vernon, 1951, p. 209) (see fig. 11).

The author has collected samples of Ocala limestone

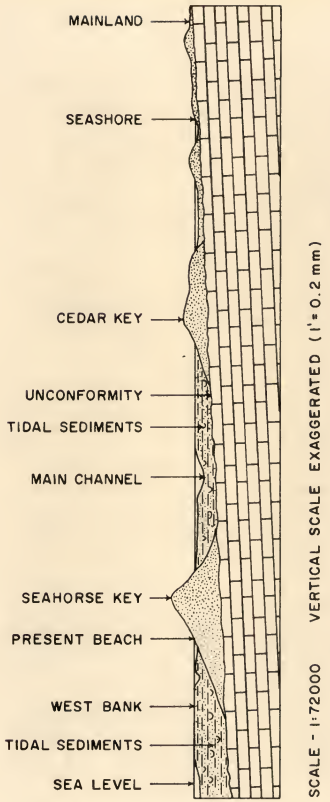

Fig. 11.--Generalized cross-section of the Cedar Keys area (diagram by H. K. Brooks).

from the channel between Snake Key and Atsena Ortie Key one mile northeast of Seahorse Key. The limestone outcrops on the bottom of the channel at a depth of approximately four meters. The author and Dr. H. K. Brooks (Geology Department, University of Florida) have taken over twelve cores in the lagoons near Seahorse Key and on adjacent banks. Basement rock was encountered at depths of 9 to 15 feet, indicating an irregular surface. Typical Ocala limestone foraminifera appeared in the bottom-most sediments, indicating that they had been reworked into the Pleistocene mud and sand (Puri and Vernon, 1964, p. 96).

Seahorse Key is predominantly composed of quartz sand. This sand was transported by the Suwannee River to the Cedar Keys area during the Pleistocene Epoch. During the glacial periods, sea level was lower than at present and wind caused the formation of dunes. Sediment analysis has indicated that Seahorse Key is a remnant dune (H. K. Brooks, personal communication). The maximum elevation of Seahorse Key is 52 feet (Seahorse Key Quadrangle, 1955). The traces of one marine terrace are manifested on the key, that being at an elevation of 8 to 10 feet. This corresponds to the Silver Bluff (Cooke, 1945, p. 248). The

Silver Bluff Terrace is associated with a post-glacial climatic optimum at about 7,000 to 6,000 years B.P. (MacNeil, 1949, p. 104). Since evidence for other terraces does not exist on the key, it must have been formed during late Wisconsin glaciation (Brooks and Ingmanson, in press).

The key appears to have undergone two erosional cycles since its formation. The first occurred at Silver Bluff time and is evidenced by an 8- to 10-foot terrace extending the key proper westward. The second is operating presently and is extending the key proper eastward. Currents in the fall and winter are the present agents of erosion, much work having been done during occasional storms with little done normally due to the low-energy sea.

The present stability of Seahorse Key is due to a combination of factors. As sea level rose following the Wisconsin glaciation, the climate moderated, producing increased precipitation and a higher water table. The higher water table and organic material enabled palmettoes and other plants to take root in the dunes. The stability is the direct result of the presence of the vegetation.

Review of the Literature

Many geologists have written extensively on the geology of Florida but few have reported on the Cedar Keys area. The two accepted authorities on the geology of the area are Cooke (1945) and Vernon (1951). A summary of the stratigraphy of the bedrock has been published by the Florida Geological Survey (Puri and Vernon, 1964). For an extensive summary of the literature applicable to the area, Vernon's Geology of Citrus and Levy Counties, Florida should be referred to. The general geology of the area has recently been reinterpreted (Brooks and Ingmanson, in press).

The literature pertaining to the measurement of chemo-physical environmental variables is scattered throughout many books and periodicals. Basic references are Farber (1962) and Strickland and Parsons (1960).

For an understanding of the biology of foraminifera, the author recommends Myers (1942a, 1942b, 1942c, 1942d, 1943) and Phleger (1960).

The identification of the species found in the samples was based primarily on comparisons with specimens reported by Bandy (1954, 1956), Cushman (1939), and Wade (1957). The taxonomy adopted by the author is based on Moore (1964).

Procedures

From September, 1963, through August, 1964, samples were collected at each of five stations located near Seahorse Key (see fig. 12). The stations were selected as representative of the shallow water bottom environments in the Cedar Keys area. Stations 1, 2, and 3 were in mud overlain by water well circulated by tidal currents; Station 4 was an oyster bar (Crassostrea virginica); and Station 5 was on a sandy bank populated by numerous sand dollars. All sampling was done between 1000 h (10:00 A.M.) and 1300 h (1:00 P.M.).

The samples were collected using the Brooks method (H. K. Brooks, personal communication) (see also section on Oxidation-Reduction) and were treated with rose bengal solution to stain the protoplasm of the living foraminifera (Walton, 1952, pp. 56-60):

1. Empty a beer can.
2. Remove the top of the can.
3. With a center punch, put a hole in the other end of the can.
4. Obtain a cork that will fit the hole.
5. Sink the can into the mud, manually, open end first.
6. Insert the cork.

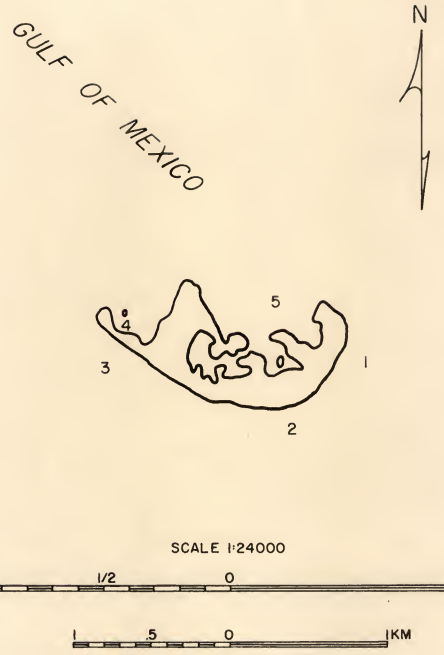

Fig. 12.--Diagram of Seahorse Key showing station locations.

7. As you remove the can, a vacuum is created and the sample remains in the can.

8. Wrap aluminum foil around the open end of the can.

9. Remove the cork, pour approximately 50 ml rose bengal solution through the center punch hole.

In the laboratory, the remaining end of the can was removed with a can opener and inserted from the opposite end, pushing the sample out. Approximately the top 1 to 1-1/2 cm of each sample was sliced, using a broad knife, into a pan and subsequently wet-sieved through a 5-mesh and 170-mesh sieve (A.S.T.M. sieve standard). The material recovered on the 170-mesh sieve was washed into a pan and the water was removed by evaporation (slight heating and standing). This residue was then floated in a solution of carbon tetrachloride. The foraminifera along with other light material floated on the surface whence it was filtered and the concentrate saved. The concentrate was brushed onto a small black tray for study purposes (see fig. 13).

The rose bengal solution proved unsatisfactory for the identification of live foraminifera. The author feels that the physical processes used to concentrate the sample

Fig. 13.--Faunal concentrate (showing abundant foraminifera, scattered diatoms, one crab claw, one ostracod).

served to dessicate the relatively unsupported foraminiferal protoplasm and destroyed some of the agglutinated tests. Pelecypods in the sample were well stained. The fact that their valves can be closed makes possible preservation of the protoplasm within the valves. The staining method used (Walton, 1952, pp. 56-60) is generally unreliable for foraminifera but reliable for other marine organisms. For the purposes of this study the total number of foraminifera was counted, and the individuals belonging to the genus Elphidium were handpicked and stored on microfaunal slides.

Temperature was measured with a standard Centigrade scale thermometer read immediately after removal from manual placement at the substrata/water interface.

Salinity was measured using a hydrometer floating in a 1000-ml cylinder of bottom water obtained manually. The density thus read and the temperature were correlated by reference to conversion tables (Zerbe and Taylor, 1953).

A Beckman model N portable pH meter was used to measure both pH and Eh. A calomel standard electrode was used for both measurements. A glass electrode functioned as the chemically inert electrode in the former case and a platinum electrode in the latter. When measuring both,

the Brooks method (see Oxidation-Reduction section) was followed.

Precise tidal ranges were taken from tide tables published by the U.S. Coast and Geodetic Survey (1963, 1964).

Light penetration was measured with a home-made photometer[1] (see Light Penetration section). The light intensity was read at the surface and set by a variable resistor to an even number on the galvanometer scale. The device was lowered to the desired depth and the reading was recorded. The submerged reading divided by the surface reading multiplied by 100 equaled the percentage of total light penetration.

Chemo-physical Data

The high- and low-water figures are for St. Mark's River entrance, which is the nearest location of published precise tidal measurements. For high- and low-water figures for St. Mark's River entrance, see table 15.

Generally a graph of the diurnal tides for the Cedar Keys area would have a major and minor crest and a major and minor trough (see fig. 14).

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[1]Built and designed by William Delcomyn, student College of Engineering, University of Florida.

TABLE 15

TIDE CHART FOR ST. MARK'S RIVER ENTRANCE

	Time	Feet (relative to mean low water)	
September 26, 1963	0040	2.3	
	0623	3.0	
	1440	0.9	
	2223	2.6	
October 19, 1963	0222	3.6	
	0902	0.0	
	1533	3.3	
	2106	1.4	
November 28, 1963	0611	-0.1	high winds (> 40 mph)
	1234	3.0	produced extra high
	1818	0.8	tides, kept tide from retreating
December 28, 1963	0642	-0.9	
	1328	2.7	
	1839	1.1	
February 1, 1964	0359	2.9	
	1035	-0.4	
	1654	2.4	
	2244	0.3	
February 28, 1964	0231	3.1	
	0836	-0.7	
	1522	2.6	
	2111	0.1	
March 21, 1964	0211	-0.3	
	1005	1.8	
	1303	1.7	
	1924	2.6	

TABLE 15--Continued

	Time	Feet (relative to mean low water)
April 18, 1964	033	-0.4
	0752	2.0
	1136	1.8
	1747	3.0
May 26, 1964	0245	3.0
	0751	1.5
	1337	3.6
2041	2041	-0.3
June 28, 1964	0459	2.9
	0943	2.0
	1529	3.7
	2246	0.1
July 25, 1964	0328	3.2
	0827	1.9
	1413	3.9
	2119	0.0
August 29, 1964	0537	3.7
	1231	0.7
	1903	2.9

Sources: U.S. Coast and Geodetic Survey, 1963, 1964, pp. 130-33 in each.

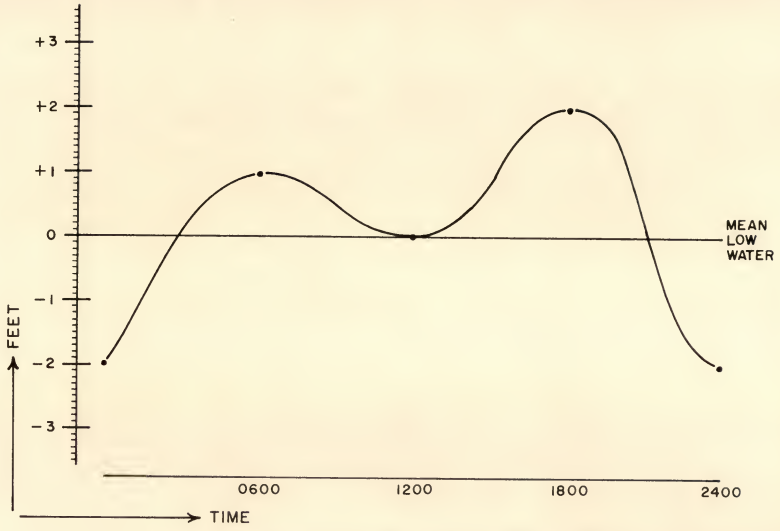

Fig. 14.--Graph of diurnal tides at Seahorse Key.

The maximum tidal range rarely exceeds four feet. Because mud flats lap onto Seahorse Key, a four- to five-foot tidal variation exposes an area 200 to 300 meters wide with isolated tidal pools. If winds are not a factor, these flats are exposed at full moon and new moon. The author has seen all five stations exposed on occasions (not always a sampling day).

The pH and Eh readings are shown in table 16.

TABLE 16

pH AND Eh FIGURES

Station 4	pH	Eh
March 21, 1964	7.50	-370 mv
April 18, 1964	7.30	-355 mv
May 26, 1964	7.90	-380 mv
June 28, 1964	7.60	-390 mv

The pH readings are slightly below the pH of ordinary sea water (8.0 - 8.3). The lower readings may be due to the influence of fresh water from the Suwannee River, which empties into the Gulf of Mexico north of the Cedar Keys. The water in the Suwannee River is comprised principally of drainage from the Okefenokee Swamp, which

is highly acidic (about 5.0 to 6.0) and springs from the Ocala limestone which varies greatly in pH (7.3 to 8.5) (H. K. Brooks, University of Florida, personal communication).

The Eh readings are somewhat inaccurate because of the difficulty of obtaining uncontaminated data in field work (see section on Oxidation-Reduction). The above figures are probably lower than figures uncontaminated data would reveal. In spite of the limitations, it can be said that the bottom is highly reducing. Eh readings were taken at stations other than Station No. 4. The figures indicated that the respective interfaces were somewhat less reducing than at Station No. 4 but could still be described unquestionably as reducing.

The temperature of the water at Seahorse Key ranged from 11.5°C to 31.5°C (see fig. 15). Slightly lower and higher temperatures could have occurred for short periods of time during the year of the study. In addition, since the stations were exposed occasionally at extremely low tides, the temperature of the exposed mud was recorded at a time when low tide occurred in the early afternoon in the summer. It was found to be 39°C (Howard Marshall, Biology Department, University of Florida, personal communication).

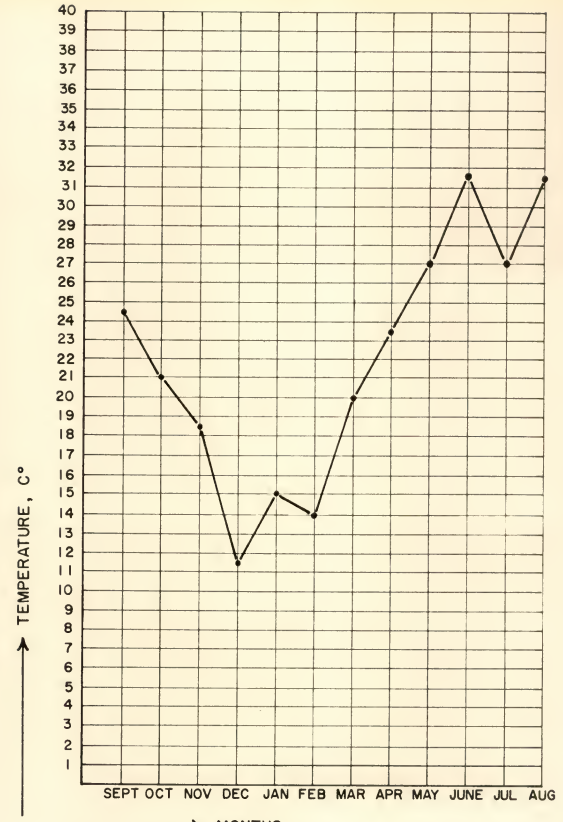

Fig. 15.--Temperature of sea water at Seahorse Key, Florida.

The salinity showed a range from 28.4 to 34.6 (see table 17). The higher salinity figures were recorded in the winter when flow from the Suwannee River is reduced and northwest winds predominate, pushing water from the Gulf of Mexico toward the shoreline. In the summer, the volume of water carried by the Suwannee River increases, and the predominant winds blow gently from the southeast, thus accounting for the reduced salinity figures.

The data on light penetration (see table 18) indicate that the water is not clear at any time during the year. Personal observation easily corroborates this fact. Since the surrounding banks are very shallow and the substrata have much unconsolidated mud, tidal currents provide enough energy to keep mud suspended in the water. In addition, a large amount of flocculated organic matter is introduced by the Suwannee River (H. K. Brooks, personal communication). These two facts are the principal causes of minimal light penetration in the area.

The data collected on dissolved oxygen revealed no anomalies. The waters are in approximate equilibrium with the atmosphere (table 19).

TABLE 17

MEAN TEMPERATURE, DENSITY, AND SALINITY
AT SEAHORSE KEY, FLORIDA

	Temperature	Density	Salinity
September 26, 1963	24.5°C	1.022	32.7
October 19, 1963	20.5°C	1.023	32.7
November 28, 1963	18.5°C	1.025	34.6
December 28, 1963	11.5°C	1.025	32.4
February 1, 1964	15.0°C	1.023	32.9
February 28, 1964	14.0°C	1.022	29.5
March 21, 1964	20.0°C	1.020	28.5
April 18, 1964	23.5°C	1.019	28.4
May 26, 1964	27.0°C	1.020	31.0
June 28, 1964	31.5°C	1.017	28.8
July 25, 1964	27.0°C	1.019	29.7
August 29, 1964	31.5°C	1.017	28.8

TABLE 18

LIGHT PENETRATION[a]

	Depth in Meters	Total Light (Percentage)	Red Filter (Percentage)
May 26, 1964	1	87	85
	2	65	56
June 28, 1964	1	88	85
	2	67	62
February 20, 1965	1	84	83
	2	61	55

[a]Taken just east of Seahorse Key.

TABLE 19

DISSOLVED OXYGEN[a]
(East Channel, Depth 6.2 Meters)

	Surface Temperature	Bottom Temperature	Surface Salinity ppt	Dissolved O_2 ppm
January 16, 1965	15.5°C	15.4°C	28.4	7.2
February 21, 1965	17.0°C	17.5°C	. .	5.5
February 27, 1965	11.8°C	11.5°C	9.7	5.0
March 6, 1965	12.0°C	12.0°C	9.3	6.0
March 13, 1965	17.2°C	16.1°C	19.2	4.1
March 20, 1965	19.2°C	19.0°C	22.5	4.2

[a]Determined by BLY 612 class using Winkle Method, University of Florida, Winter Trimester, 1965, Dr. E. L. Pierce.

Biological Data

The population of foraminifera at all stations fluctuated considerably during the course of the study (see table 20). The most specimens tended to be found in the winter months with a maximum population reached in the late winter and early spring and a minimum in the summer months. February yielded the largest population of the year. The most specimens in each month were found at Station No. 4, which was located in a lagoon on an oyster bed. The station with the least specimens varied from month to month among stations other than No. 4.

The most common species were:

1. Elphidium gunteri Cole (see fig. 16)
2. Streblus beccarii (Linné) var. sobrinus (Shupack)
3. Anomalina io (Cushman)
4. Elphidium poeyanum (d'Orbigny) Cushman (see fig. 16)
5. Quinqueloculina dutemplei D'Orbigny
6. Laryngosigma hyalascidia(?)

These six species represent approximately 80 per cent of the total specimens found. They have all been reported in the Gulf of Mexico area except for Laryngosigma hyalascidia, which has heretofore been reported from the Arctic (Loeblich and Tappan, 1953, p. 83).

TABLE 20

FORAMINIFERAL POPULATION FIGURES

	Stations	Elphidium	Others	Total per Station	Total per Month
Oct.	1	4	81	85	
	2	2	87	89	
	3	13	128	141	
	4	117	681	798	
	5	23	507	530	1,643
Nov.	1	35	302	337	
	2	43	240	283	
	3	45	38	83	
	4	407	987	1,394	
	5	131	395	526	2,623
Dec.	1	49	240	289	
	2	6	162	168	
	3	44	191	235	
	4	353	1,239	1,592	
	5	150	367	517	2,801
Jan.	1	214	912	1,126	
	2	6	155	161	
	3	10	527	537	
	4	345	882	1,227	
	5	29	236	265	3,316
Feb.	1	288	302	590	
	2	32	739	771	
	3	39	508	547	
	4	535	2,054	2,589	
	5	73	168	241	4,738

TABLE 20--Continued

	Stations	Elphidium	Others	Total per Station	Total per Month
March	1	164	127	291	
	2	71	233	304	
	3	55	130	185	
	4	516	921	1,437	
	5	47	50	97	2,314
April	1	93	125	218	
	2	37	292	329	
	3	54	82	136	
	4	1,070	1,785	2,855	
	5	76	79	155	3,693
May	1	405	126	531	
	2	48	451	499	
	3	69	158	227	
	4	483	1,165	1,648	
	5	135	366	501	3,406
June	1	28	58	86	
	2	20	248	268	
	3	13	64	77	
	4	255	533	788	
	5	90	204	294	1,513
July	1	19	54	73	
	2	21	231	252	
	3	12	58	70	
	4	213	501	714	
	5	103	314	417	1,526
Aug.	1	10	47	57	
	2	18	189	207	
	3	5	23	28	
	4	106	489	595	
	5	92	304	396	1,283

Fig. 16.--Top: Elphidium gunteri Cole;
Bottom: Elphidium poeyanum (d'Orbigny) Cushman.

Conclusions

The fluctuation in population of foraminifera at Seahorse Key, Florida, as indicated from the data of this study is controlled by several factors. The major factor causing reduced populations in the summer is probably the extremely high temperatures in exposed substrata when low tide occurs in the middle of the day in the summer. A sustained water temperature of 34°C is lethal to Crassostrea virginica in Florida (Hedgpeth, 1957, p. 172). Since oysters can close their valves in an attempt to combat environmental changes, they can probably endure higher temperatures than foraminifera. A temperature of 39°C even over a short time may be lethal to foraminifera. More research on this hypothesis is needed.

The largest population was consistently at Station No. 4. The data reveal two anomalous ecologic factors at this station. First, the Eh (oxidation-reduction potential) was extremely low (at least -390 millivolts). Apparently the most common species of foraminifera in this area thrive in a highly reducing environment. This may be related to less predation in highly reducing environments. Second, oysters (Crassostrea virginica) were at this station. Possibly the foraminifera use oyster fecal pellets

as a source of nourishment. Examination of cultures of live foraminifera from the area revealed large dark spots in the protoplasm which may have been fecal pellets. More research is needed to validate these two hypotheses.

CHAPTER V

PLANNING FIELD WORK

Most young people love being outdoors. To them, the outdoors signifies freedom, fun, and the chance to explore. Few children look upon the outdoors with anxiety or hostility; it is the friend of youth. Young people learn a tremendous amount simply through everyday interaction with the natural world, and they enjoy it. Teachers, particularly science teachers, who do not or cannot take advantage of the educative opportunities available in the natural world are restricting their role in the job of teaching students. Since the fundamental basis of all science, if not all things, lies in nature,[1] this is the subject matter teachers should begin with in educating youth. Teachers should use nature as a base from which to operate and should continually refer back to it in an attempt to help students relate the things they learn to a meaningful conception of the world as they see it.

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[1]Nature here is referred to in its broadest sense.

Most people have some concept of the term "field trip." To most students, it means the opportunity for something different and a chance to do something besides sitting still in class. To most teachers, it means a disciplinary nightmare but a chance to be popular with the students. To most administrators, it means an extension of their responsibility for the welfare of the students beyond the limits of the school grounds and the expenditure of too much money. The result is that field trips are a rare occurrence in public school systems.

> The term "field trip" is commonly used to designate any organized visit to points outside the classroom, taken by school people as an integral part of their academic work, and primarily for educative purposes [Olsen, 1954, p. 206].

Based on this definition, "doing field work" is a more apt expression than "taking a field trip."

School and Community (Olsen, 1954) gives an annotated bibliography of literature related to field work. The bibliography is listed in categories: (1) the origin and development of school excursions, (2) case studies pertaining to any grade level, (3) relevant to elementary school, (4) relevant to secondary school, and (5) relevant to college. Individualizing Instruction (Doll, 1964) discusses the teaching approach which can best utilize field

work as a source of enrichment through emphasizing student involvement, exploration, and discovery. Group Planning in Education (Misner, 1945) presents ideas for effective planning which in themselves offer important educative results.

There is a variety of types of field work, and the choice depends upon the purposes of the work and what the people involved hope to accomplish. Regardless of the choice, field work introduces realism to school activities. Especially relative to the near-shore or any marine environment, observing the natural relationships is of great importance in understanding the physical, chemical, and biological conditions controlling the environment. The best way a teacher can help a student develop an integrated concept of the natural world is to go into the field with the student, ask and answer questions, and encourage accurate observation and interpretation.

There may be any one of a number of reasons why field work is desirable. Among them are: "securing information, changing attitudes, awakening interests, developing appreciations, promoting ideals, enjoying new experiences" (Olsen, 1954, p. 207).

Field work, in general, is an ideal source of

enrichment for the curriculum. This enrichment is on two levels -- increasing a student's concept of the structure of the subject matter of current study, and encouraging a student's interest in and understanding of the natural world. Field work in the near-shore marine environment provides a double source of enrichment, because the enthusiasm of students for both field work and the ocean is generally high.

Worthwhile field work in the marine environment may be accomplished in a few hours, a day, several days, or periodic visits. The amount of time required varies with the amount and type of work to be done.

The use of field work is appropriate when classroom activities are inadequate to achieve the specific goals set by the students and the teacher relative to the subject matter. The initiation of the idea for field work may come either from the students or the teacher. If the whole class, including the teacher, reaches consensus that only through field work will their goals be reached, then field work involving the whole class is appropriate. To justify the use of school time, field work should generally be a class activity. If only a few students are interested and the teacher consents, field work outside of

school time is appropriate. Classes larger than twelve to fifteen can be difficult to control in any kind of outdoor endeavor, in which case the selection of a group designated by the class to do the field work and present the results to the class can be valuable.

Careful preparation and organization, along with clear understanding by all of the purposes of the work, are essential to the accomplishment of successful field operations. It is important for each involved to know what is expected of him in terms of work and behavior.

In preparing for field work, the first task is for the teacher to find out the relative attitudes and policies of the school. If the work is done on school time, the school is responsible for the welfare of the students. The extent of the responsibility of the school, especially in terms of insurance coverage, should be clear to the teacher, the students, and the parents. Inadequate coverage puts the responsibility on the shoulders of the teacher. Some insurance policies offer extended coverage especially for teachers at very little extra cost. Consultation with reputable insurance agents may be wise. Parents should then be notified, and plans should not continue unless approval is granted in written form and submitted to the principal.

The second step involves class discussion. Often discussions participated in by the whole class are unwieldy. Division of the class into committees assigned with specific planning tasks to be reported to and agreed upon by the whole class at a later time is most successful. Tasks that are part of the planning include: (1) stating of the specific purposes for the work, (2) arranging for adequate transportation, supervision, and safety, (3) choosing the locality for the work, and advance reconnaissance, (4) delineating and personnel assignment of specific tasks to be carried out during the field work, (5) obtaining gear needed, (6) obtaining any permission required to visit private property, or notifying officials if visiting public property, (7) estimating personal expenses and appropriate clothes, food, and gear, and (8) developing a general guide sheet for all participants. Any of these tasks can be assigned to committees.

The specific purposes of the field trip should be in terms of the relation of the proposed work to previous classroom activities out of which the desire for field work grew and what the projected expectations of the work are. Field work need not arise from prior classroom activities. Sometimes field work can be the introduction and impetus to many future classroom activities.

The safety of the students at all times is of paramount concern. Transportation should be safe, with room for everyone. Adequate supervision is a necessity, especially for students unable to cope with emergencies. Although it is highly undesirable, there may be times when the teacher is not around. Students below senior high school level should always have adult supervision in field work. Additional supervision can be provided by other teachers, parents, friends, or older students (above age sixteen).[1]

The reconnaissance of various localities to insure their accessibility in terms of available transportation and desirability in terms of characteristics is important. Often many localities may be visited, among which only a few will meet the needs of the group. In addition, the teacher should review in advance the significant aspects of a locality so that he can help the students interpret the prevailing and prior conditions.

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[1]The author was held for fishing illegally once while conducting field work alone with junior high school students. The group was obtaining samples of animal life with a net. The author was faced with the choice of leaving the students at the locality for a period of time or taking the students to the police headquarters. To avoid such a dilemma (1) local officials should have been notified previously of the activities, and (2) another adult should have been present.

The delineation of the tasks to be done and the delegation of the tasks to individuals or groups contribute to efficient work. Seldom can field work be duplicated, so all the data desired must be obtained in the time allotted. This also entails listing the gear needed for accomplishing the tasks. Some people may be able to supply personal items such as knives, hand lenses, or collecting jars. The school may have equipment available. Occasionally, students will have to build items to collect data (Chapter III) or borrow from local resources.

Private property often reveals the best localities because it has been disturbed by man less than public property. Representatives of the group should communicate, in person if possible, with the owner of the property asking his permission to operate and informing him completely of the proposed activities. If the approach is polite and the purposes are clearly communicated, owners tend to be very cooperative.

The police or other local authorities should be notified in advance of the proposed work. They can be helpful in supplying safety and pertinent information. Often they can recommend local people who can supply information about the history of a locality. "Old-timers" are

an important source of information, not to mention the fact that they are interesting to talk with.

A general guide sheet summarizing the whole operation helps the individual students keep everything in perspective. This guide should clearly summarize the purposes of the work, anything of interest en route, and specific activities to perform and features to notice at each locality. If one of the specific purposes of the work is to determine the controlling environmental variables at a particular locality, the guide can list a series of questions designed to help the student structure his approach to the problem. The guide may also contain a brief summary of conclusions made by previous investigations at the same locality. Room should be provided in the guide for the student to make his own comments.

Often, much has to be accomplished in a relatively short period of time. The teacher should be sure that the number of activities is limited to a reasonable degree in the light of the time, needs, and capabilities at hand. Hurried field work increases the chance of error in data collection, the chance of accidents, and the chance of inadequate integration by the students of what is going on, how, and why.

Before going into the field, the students should be clearly aware of the leadership role of the teacher. All field work must be accomplished under authoritarian procedures in the interest of discipline, safety, and efficiency. This does not mean that there will be no time to contemplate, enjoy oneself, or ask questions. The success of field work depends in large part on the acceptance of a capable leader. Field work can be fun, but once a participant leaves the group on his own, the work is disrupted and the welfare not only of the alienated participant but also the group is at stake. It is for this reason that there must be one accepted leader who can and will assert himself when necessary.

If planning has been accomplished thoroughly and all participants feel they have contributed to the planning, operating procedures while in the field should run smoothly. Before departure, the leader should meet with the group to review tasks, expectations, purposes, and any questions. The enthusiasm of the students generally reaches its peak at this point. A good leader should remind participants of his role before departure while enthusiasm is high, especially with groups larger than twelve to fifteen. Generally, the review session is sufficient reminder. The leader is

also responsible for last-minute checking of the number of participants and of the gear needed. This checking can be delegated to others.

During the course of the field work, the leader should present his lectures clearly and concisely, be ready to answer questions, and be alert for stragglers or accidents. If individual tasks have been previously assigned, the leader's role is mainly to be alert for accidents. Often students become momentarily overwhelmed by the complexity of relations in the field and "just don't know where to begin." The leader must watch carefully for signs that individuals are proceeding aimlessly with their work. These individuals need his direction.

The leader should check periodically with the students to insure that satisfactory progress is being made or to answer questions that may have arisen in the course of their work. This checking will help the leader keep progress on schedule if time is a factor.

Before leaving a locality, the leader should summarize the facts obtained or observed and again answer any questions. In addition, he should make sure everyone has completed his tasks and is ready to move on. A re-checking of the number of students and gear should be made at each locality.

Upon return to the point of adjournment and departure, the leader should review what has been accomplished and entertain further questions.

The classroom activities that follow any field work are an important part of the educative value of the work. These activities should be structured to allow the students to share their data and conclusions with one another through discussion. The students may want to select a committee to compile the acquired data and conclusions so that each individual can see the results of the work in an integrated form. These results may be presented by the committee to the class in written and oral form. Included in this presentation should be an evaluation of the field work stating the extent to which the planned purposes were met and suggesting ways of improving further field work.

Provision should be made to communicate appreciation to contributors from outside the school. Letters of appreciation lay the foundation for continued cooperation and good will.

Generally, many questions arise from field work. A list of these questions presented by the summary committee or the class is a valuable source of ideas for further

classroom activities. For instance, the discovery of minimal light penetration in a near-shore marine environment may lead to a wide range of further activities ranging from the investigation of local pollution problems to the study of optics.

In summary, field work provides a stimulating source of enrichment for any science class. A variety of outcomes, including the acquiring of data and the opportunity to provide meaningful new experiences for students may justify field work. Complete and efficient planning using democratic procedures produces successful field work. A leader empowered with authority makes operating procedures in the field run smoothly and effectively. Classroom follow-up enables the student to integrate everything that was observed and obtained and leads him to further study.

CHAPTER VI

CONCLUSION

The marine sciences represent an expanding frontier of knowledge. Current research indicates that the oceans will be an important source of fresh water, food, and minerals. Research in the marine sciences is now dominant, but development of the economic potential of the oceans is in progress promising increased employment through research, development, and production. Progress in the marine sciences is rapid because of support by the government, independent foundations, cooperative university projects, and public interest. The school curriculum should reflect the emerging role of the marine sciences in the spectrum of the explosion of knowledge.

The marine sciences represent an area requiring interdisciplinary cooperation utilizing the knowledge of biologists, geologists, chemists, physicists, meteorologists, and engineers. As a reflection of the necessity of an interdisciplinary approach to the investigation of

the oceans, the public school curriculum should include specific aspects of the marine sciences in the structure of disciplines already constituting the curriculum.

The combination of economic importance and high public interest projects the marine sciences into a position of prominence in our everyday lives. Since interest is high and because of the interdisciplinary nature of the marine sciences, they offer an excellent source of enrichment of present subject matter within the curriculum.

The role of the marine sciences in the public school curriculum is considered in Chapter II. First, the factors which have combined to elicit changes in the curriculum are discussed. Second, the inclusion of the marine sciences in the curriculum is analyzed in terms of proposed criteria for deciding what to teach: (1) human development, (2) social forces, (3) nature of knowledge, and (4) the structure of knowledge (Hass and Wiles, 1965, pp. 3-310). The inclusion of the marine sciences in the curriculum is considered from the point of view of its relation to established courses and current curriculum innovations.

The near-shore marine environment offers to the public school a readily accessible source of opportunities for acquiring information, introducing new experiences,

stimulating interest, and encouraging exploration and discovery. Specific environmental variables appropriate for interpreting cause-and-effect relations in the near-shore marine environment include currents, tides, temperature, substrata, salinity, light penetration, hydrogen ion concentration, oxidation, reduction ratio, and dissolved oxygen content. Chapter III discusses each of these variables from the point of view of their nature, identification, measurement, relation to marine life, and specific role in the science curriculum.

Chapter IV presents a research model which reflects the utilization of the variables and methods discussed in Chapter III in the investigation of near-shore marine ecologic conditions at Seahorse Key, Florida. The data are presented and interpreted in a clear and concise form. The study has revealed important new discoveries relating to ecologic conditions in the near-shore environment and to the study of foraminifera.

Field work, discussed in Chapter V, is an important aspect of scientific endeavor. Too often scientists, especially physicists and chemists, forget that the basis of science is the natural world. Suggestions are made in Chapter V concerning the role of field work in the science

curriculum and the organization, execution, and follow-up of field work.

This dissertation is designed primarily as a resource for teachers desiring to use the marine environment as a field laboratory to aid and enrich their classroom teaching and for students interested in doing elementary research in the marine environment. The dissertation is especially related to the marine environment, but the techniques and suggestions will have value wherever seas, lakes, or rivers could be used as field laboratories or locations for research.

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BIOGRAPHICAL SKETCH

Dale Eugene Ingmanson was born in East Orange, New Jersey, on July 5, 1938. He lived in Rahway, New Jersey, for three years. The next two years, he lived in Summit, New Jersey. From 1944 until 1956, he lived in New Haven, Connecticut, where he attended Hamden Hall School, from which he was graduated in 1956. From 1956 to 1960, Mr. Ingmanson attended Rollins College in Winter Park, Florida, from which he received a Bachelor of Science degree in geology in 1960. He attended Rutgers University from 1960 to 1961, receiving a Master of Education degree in 1962. In 1961, he taught at Howard Junior High School in Orlando, Florida. He entered the University of Florida in the fall of 1962, holding successively one-third time graduate assistantship, one-half time interim instructor, and full time interim instructor until 1965. Currently, he is instructor of science at Southern Connecticut State College in New Haven, Connecticut.

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This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Education and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Education.

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